Kaunas University of Technology

Faculty of Mechanical Engineering and Design

Sustainable urban logistics solutions for the city of Kaunas

Master's Project (PR00M115)

Department of Transport Engineering

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Declaration of Academic Integrity

I confirm that the final project of mine, José María Sitges Vernis, on the topic "Sustainable urban logistics solutions for the city of Kaunas" is written completely by myself; all the provided data and research results are correct and have been obtained honestly. None of the parts of this thesis have been plagiarised from any printed, Internet-based or otherwise recorded sources. All direct and indirect quotations from external resources are indicated in the list of references. No monetary funds (unless required by Law) have been paid to anyone for any contribution to this project.

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Summary

The main objective of this research project is to develop sustainable measures for the improvement of urban logistics in the city of Kaunas. The project is focusing on the sustainable approach to evaluate the viability of its measures. In other words, it considers the feasibility of the measures depending on the social, economic, and environmental effects that they could have.

Firstly, it is analyzed the problems caused by logistic activities in Kaunas. Some of the problems have deep consequences for Kaunas citizens and might even be worse in future scenarios.

The analysis tries to draw all the logistic scenario existing in the city. Kaunas, as an important logistic "pole" of Lithuania, has some important logistic platforms that must be considered. Besides, it is also analyzed different levels of administration, the developed plans of each of them, and the stakeholders related to different economic activities.

To conclude the analysis and provide a more extended context, it is done a benchmarking of different successful measures developed in other cities.

Finally, it is proposed two related measures. In the first place, it is located an urban distribution center by using *Brown & Gibson Methodology* and *utility* function. Secondly, it is developed a bicycle logistic system for the operation of the located distribution center. By using *Clarke & Wright* algorithm, it is designed the capacity and the necessary routes to serve the potential demand of the urban distribution center.

Acknowledgments

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I want to thank Dr. Žilvinas Bazaras for believing in me and supervising my project.

Finally, I want to thank all people who have support me during the long hours that I have been working on my project. Especially to Elenita, Andreita, and Marcos. As the Spanish proverb says.

"Nadie es profeta en su tierra." – Popular knowledge.

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Terms:

E-commerce – E-commerce can be defined generally as the sale or purchase of goods or services, whether between businesses, households, individuals or private organizations, through electronic transactions conducted via the internet or other computer-mediated (online communication) networks. The term covers the ordering of goods and services which are sent over computer networks, but the payment and the ultimate delivery of the goods or service may be conducted either on- or off-line.
EU-28 – The European Union (EU) consists of 27 member states (28 with the UK that left the UE in 2020). Each member state is party to the founding treaties of the union and thereby shares in the privileges and obligations of membership. Unlike members of most international organizations, the member states of the EU have agreed by treaty to shared sovereignty through the institutions of the European Union in some (but by no means all) aspects of government.

Elevated pollution - The so-called "elevated" contamination has its origins mainly in the rubbing of the wheels with the pavement and the wear of the brake pads. In driving, vehicles lift these particles, and those that may have been deposited on the asphalt, back into the air.

Last Mile distribution – The movement of goods that accounts from distribution centers to its final destination. It represents the last stage of outbound supply chain logistics and represents the intrusion of freight transport into urban areas.

Lead Time - A lead time is the latency between the initiation and completion of a process. Depending on the scenario the term can represent different periods of time. With reference to this project it will represent the period between the customer orders and the delivery to the customer.

Introduction

E-commerce has had an important impact increasing and accelerating the globalization of markets, the creation of global supply chains and the flows of freight circulating all around the world. Products take part in long international supply chains till they arrive to customers. Cities are the main poles of attraction of a great part of all these products that are travelling around the world. In many cases, cities represent the final destinations of global supply chains where a wide range of logistic activities take part striking citizens welfare and adding more pollution to cities environment.

This project aims to be part of the solution of this huge problem. Of course, the present project will not solve the problem at all, but it wants to represent a little step to achieve the solution, and why not, an inspiration for others rethinking more sustainable cities.

Some European cities are receiving penalties due to their high levels of air pollutants. However, there are also many others like Kaunas that frequently maintain harmful levels of air pollution. In addition, traffic in cities also causes negative impacts on the health of citizens. These are seeing how their quality of life is diminished, as more space is granted to vehicles.

In this scenario where social welfare, environment, and economic development must grow hand in hand it will be very important to establish collaboration frameworks to generate sustainable solutions for logistic activities.

As it will be seen, the planning of logistics activities in a city needs an organized process to be developed. In the first place, it requires from a deep analysis to understand all problematics. Secondly, it is necessary to identify all the agents (administrations, companies, etc.) and the key elements (plans, policies, infrastructures, etc.) involved in the activities' processes. In the third place, it is important to observe what are other cities that are facing the same problems doing. And to conclude, it is important to develop feasible measures.

1. Understanding the problematic

As will be seen later, the transport sector is an important sector within the Lithuanian economy. However, despite representing a key element for the country's development, like many other industries, the transport sector also originates certain problems.

European cities like Kaunas, are experiencing an increase in the number of freight transports that happen inside the urban areas. But this is not a random fact; the cause of this increase is due to both e-commerce growth and the change of habits in the consumer's behavior. "Purchasing goods and services online has become a common practice among many people around the world. Some choose to make online purchases for convenience, others because of the competitive price offered by some e-commerce platforms. Regardless of the reasons for purchase, the number of digital buyers is on the rise." (Me-commercer.eu, s.f.)

One evidence of this change is the appearance of the e-commerce giant, Amazon, as the world's most valuable company. The acceleration of the digital transformation has also generated an increasingly dynamic scenario in the e-commerce landscape. New opportunities have emerged to unlock the potential of e-commerce to potentially boost growth and consumer welfare. "In the EU-28, during the period 2008 to 2018, the percentage of enterprises that had e-sales increased by 7 percentage points, from 13 % in 2008 to 20 % in 2018. Similarly, the enterprise turnover generated from e-sales increased by 6 percentage points during the same period, namely from 12 % in 2008 to 18 % in 2018." (Eurostat, Dec. 2019)

Additionally, as may be seen in *Chart 1*, the evolution of retail e-commerce sales around the world is experimenting with a big increase. Also, it may be seen that the perspective is to almost double the volume of sales in just 4 years. This is because since a lot of consumers are getting used to buying through this channel, new companies and business models are flourishing, and also the payment methods are increasing its reliability.

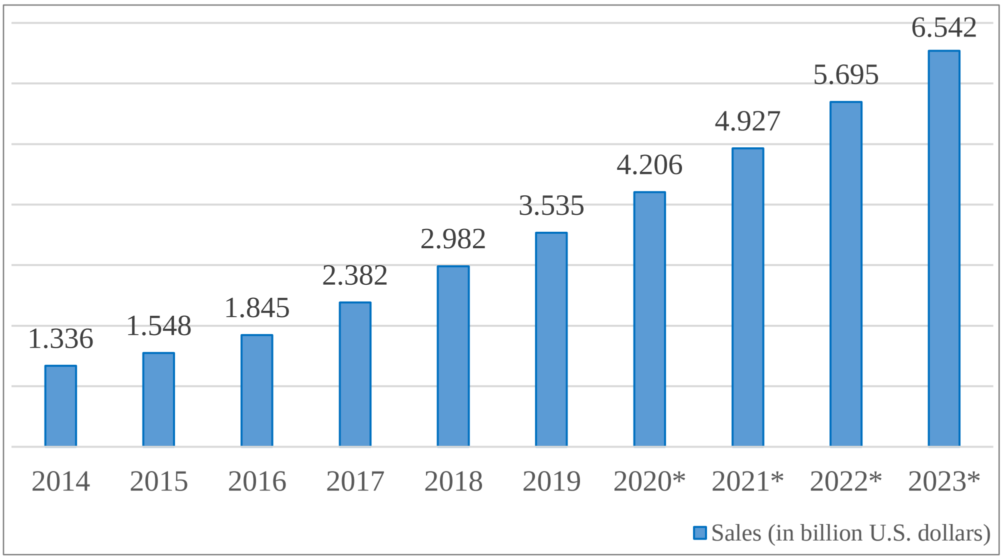

Chart 1: Retail E-commerce sales worldwide from 2014-2023.
Source: Statista.com, 2020.

In this new consuming landscape, customers have raised their requirements. In that sense, it is no longer the customer who moves to the retail stores to find the products, but the products which are transported to every customer. As well, many consumers are constantly demanding shorter cycle times from the moment they order a product since they received it. For this reason, companies are dealing with more complexity at the time of planning their shipments. Therefore, transport and logistics have gained great significance to ensure a good sale service.

It is worth mentioning that even if the wide variety of products and the fast and save online shops are having a positive impact on social welfare, the whole situation is at the same time triggering towards an important negative impact: air pollution, noise pollution, and traffic congestion being these problems caused by the increase on the volume of freight transport in the urban areas.

This chapter will focus its attention on these problems and its evolution during the past few years in the city of Kaunas. Although these issues are generally more related to big European capital cities in which the effects are heavier, Kaunas is not an exception.

1.1. Air pollution

Air pollution is one of the most worrying matters in terms of the negative implication of intensive road transport in Kaunas' urban areas. As it is well known, the world is facing a huge challenge against climate change. Europe wants to lead this battle and has set the so-called "European green deal" in order to reduce its environmental impact and move to a cleaner model. The need for expanding European economies to be more competitive in the globalized landscape collides with the need to reduce the environmental impact of the countries. So far, the greenhouse gas emissions keep growing as the increase in the volume of freight transport. What is more, not only the environment is being affected by greenhouse gas emissions, but also citizens of the big European cities who coexist every day with harmful levels of pollutants in the air. This section will try to explain evidence of the serious effects that are a direct consequence of transport activities.

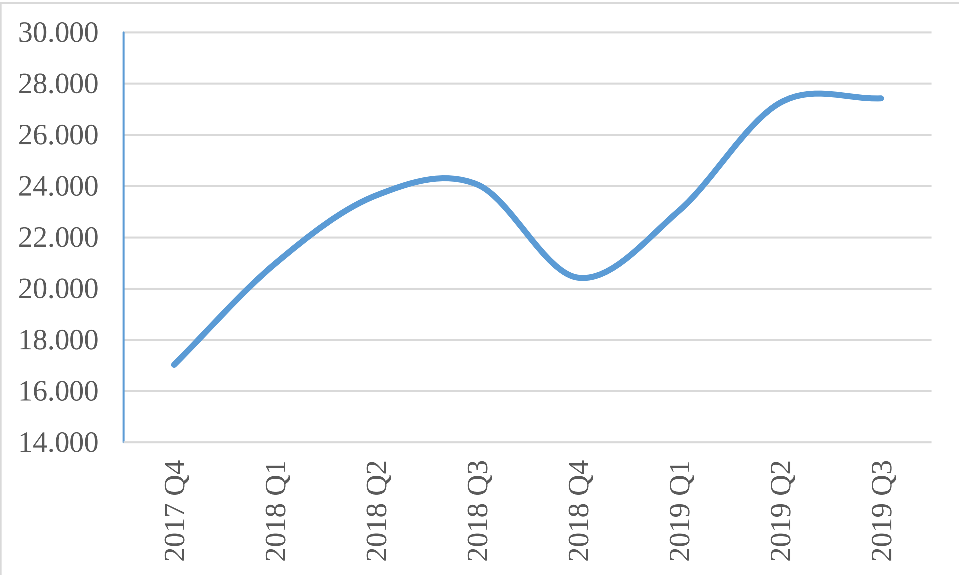

Chart 2: Kaunas Total goods transport by road (in thousand of tonnes)
Source: Official Statistics Portal of Lithuania https://osp.stat.gov.lt/

The growth of the number of carried goods in the city of Kaunas (see *Chart 2*) is also pushing an increase in the number of emissions in Kaunas. In that sense, in *Chart 3* it may be seen the emissions generated by the fuel combustion activities. Road transport activities are the ones that generate higher levels of greenhouse gas emissions. During 2007 the emissions generated by transport road were doubling the emissions of energy industries. Considering the weather of Kaunas, known by its long periods of cold temperatures, it goes without saying that the energy waste is notable, and therefore, the magnitude of emissions achieved by road transport is very significant.

Also, it is noticeable in Table 1 that the great part of the emissions come from CO. This is because in

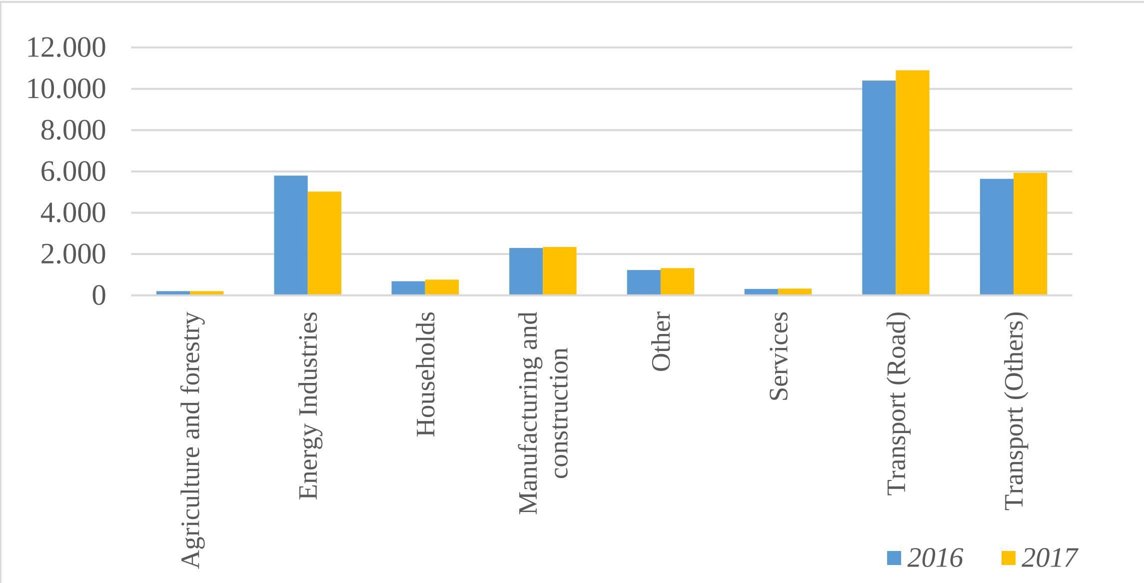

Chart 3: Tones of greenhouse gas emissions produced by fuel combustion in the city of Kaunas. Source: Official Statistics Portal of Lithuania https://osp.stat.gov.lt/

both diesel and petrol engines, during the fuel combustion, the major originated gas emissions are coming from CO. European engine regulations can be good evidence of this fact see Table 2).

Table 1: Road transport gas emissions in the city of Kaunas.
Source: Official Statistics Portal of Lithuania https://osp.stat.gov.lt/

	CO	CH_4	NO
2016	10.398,75	1,61	0,2
2017	10.889,56	1,49	0,18

In the last 10 years, the introduction of new European regulations has led to a decrease in air pollution caused by transport. Table 2 shows an example of these implemented regulations. A lot of cities are establishing traffic restrictions based on these regulatory standards. One clear example is the city of Barcelona who is imposing traffic restrictions on all those vehicles older than Euro 2.[1] However, the increase in the number of vehicles and the number of travels has continued creating undesirable greenhouse gas emissions in road transport.

[1] Low Emissions Zone of Metropolitan Area of Barcelona. https://www.zbe.barcelona/en/zones-baixes-emissions/vehicles-afectats.html

Table 2: European regulations on emissions for industrial light vehicles ≤ 1305 kg (without HC)
Source: Regulation (EC) No 715/2007 *HC (Hydrocarbons)

Regulation	Date	CO		HC*+NO_x		NO_X		PM	
		Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
Euro 1	06/1992	2,72	2,72	0,97	0,97	-	-	0,14	-
Euro 2 IDI	01/1996	1,0	-	0,70	-	-	-	0,08	-
Euro 2 DI	01/1996	1,0	-	0,90	-	-	-	0,10	-
Euro 2	01/2000	-	2,2	-	0,5	-	-	-	-
Euro 3	01/2005	0,64	2,3	0,56	-	0,50	0,15	0,05	-
Euro 4	01/2009	0,50	1,0	0,30	-	0,25	0,08	0,025	-
Euro 5	09/2009	0,50	1,0	0,23	-	0,18	0,06	0,005	0,005
Euro 6	09/2014	0,50	1,0	0,17	-	0,08	0,06	0,005	0,005

European Environment Agency advises of the bad consequences that air pollution caused by transport is having in the population of main European cities. Atmospheric contaminants like particulate matters (PM) or nitrogen dioxide (NO_2) are having harmful effects on citizens and the environment. As may be seen in **¡Error! No se encuentra el origen de la referencia.**, there are a considerable number of deaths attributed to $PM_{2,5}$. Fortunately, Lithuanias' rate of deaths/population, is still low than the average rate of EU-28.

Table 3: Premature deaths attributable to PM2,5, NO2, and O3 exposure in Lithuania and EU-28 (2016).

Source: European Environmental Agency (2018)

	Population (1000)	$PM_{2,5}$		NO_2		O_3	
		Annual mean (µg/m^3)	Premature deaths	Annual mean (µg/m^3)	Premature deaths	SOMO35 (µg/m^3·days)	Premature deaths
Lithuania	2.889	10,9	1700	12	60	2773	60
EU-28	506.028	12,9	374.000	16,3	68.000	3.547	14.000

The evaluation of air pollution levels in the city of Kaunas is measured by two equipment. One is located in Noreikiskes on the outskirts of the town, whereas the other is located in Petrašiūnai, an urban area a little bit far from the city center (see *Figure 1*). When evaluating the air quality of Kaunas

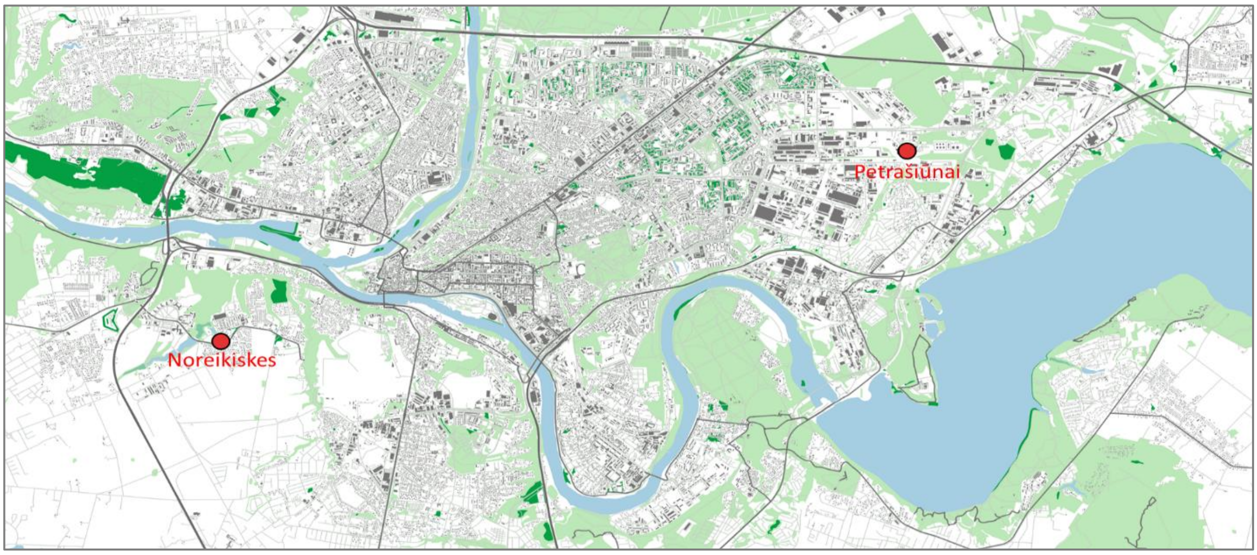

Figure 1: Air quality measuring stations in Kaunas.
Source: Own elaboration according to data from Openstreetmap

-which will be further explained- it has only been considered the measuring equipment of Petrašiūnai. Due to its position, this station is a better representation of the air that citizens are breathing and living with, and therefore provides more reliable data about the air quality in the city center of Kaunas.

The main objective of these measuring stations is to set control on the Kaunas air quality. As in many other cities, Kaunas is experimenting with episodes of high air pollution. This station allows to register these episodes and monitor the quality of the air. This project has its main focus on the most common health harmful pollutants, which are mainly diesel and petrol combustion engines. These gases are PM10, and PM2,5, CO, and NO2. The results obtained are set out below.

1.1.1. Particulate matter

Particulate matter (henceforth PM) is one of the most health harmful air pollutants. The effects of PM on health occur at levels of exposure currently being experienced by many people both in urban and rural areas and in developed and developing countries. It is worth mentioning that exposures in many fast-developing cities today are often far higher than in developed cities of comparable size. "Even in the European Union, where PM concentrations in many cities do comply with guideline levels, it is estimated that average life expectancy is 8.6 months lower than it would otherwise be, due to PM exposures from human sources." (World Health Organization, 2018).

- **PM_{10}**

PM_{10} is a particulate matter of 10 micrometers or less in diameter. Despite the origin of this particulate can also be dust from construction sites, landfills and agriculture, wildfires and brush/waste burning, industrial sources, wind-blown dust from open lands, pollen and fragments of bacteria, it's origin is also commonly related with the combustion of gasoline, oil, diesel or fuel. "Transport emissions are making a noticeable difference in weekends or ordinary working days. The particulate concentrations are higher during working days and lower at non-working days. What is more, during the warm season and especially in spring this pollutant increases in the air due to so-elevated pollution, which is also associated with transport, although it is not vehicle emissions, but dust from cars passing dirty streets or sidewalks." (Aplinkos apsaugos agentura, V. Bimbaitė, 2019).

Prolonged or repetitive exposure to PM_{10} can cause harmful effects on the respiratory system of the person, however, they are less harmful than $PM_{2,5}$ since, having a larger size, they do not manage to cross the pulmonary alveoli, being retained in the mucosa (lining the upper respiratory tract).

As *Chart 4* illustrates, PM10 has experimented a slight decline in its tendency line for this las 10 years; however, in the last 3 years, it has undergone a significant increase. The average annual concentration during the year 2019 is just one point behind the last ten years' highest concentration (2014). Likewise, the annual average values are located behind the EU limits but over the quality standards set by the World Health Organization 2005 Guidelines.

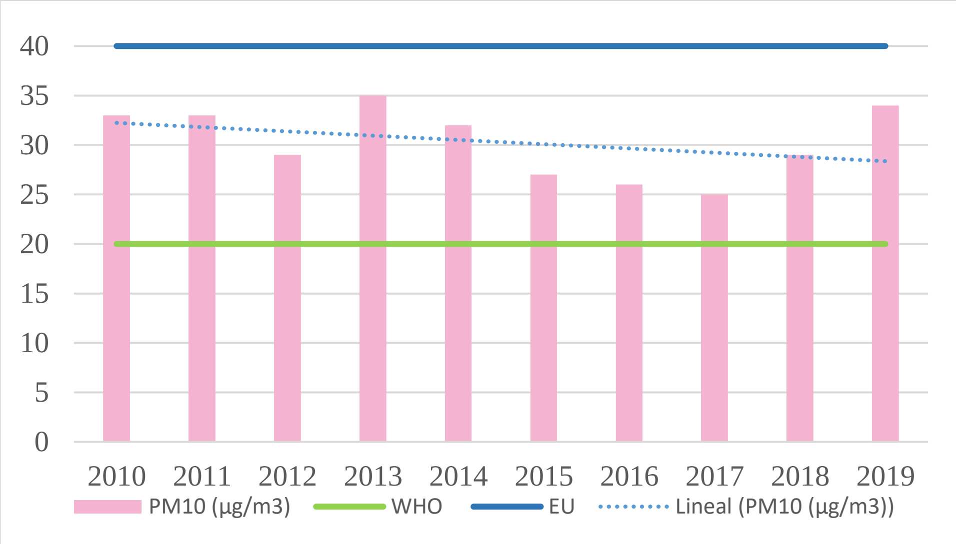

Chart 4: Average annual PM_{10} concentration Petrašiūnai station (Kaunas)
Source: Aplinkos apsaugos agentūra (25/02/2020 Air Quality Assessment Unit)

It is also important to consider the number of days that PM_{10} concentration level has been higher than the EU set regulations. This indicator gives a measure of contamination scope in the city. Or in other words, for how long the citizens have to coexist with harmful atmospheric conditions.

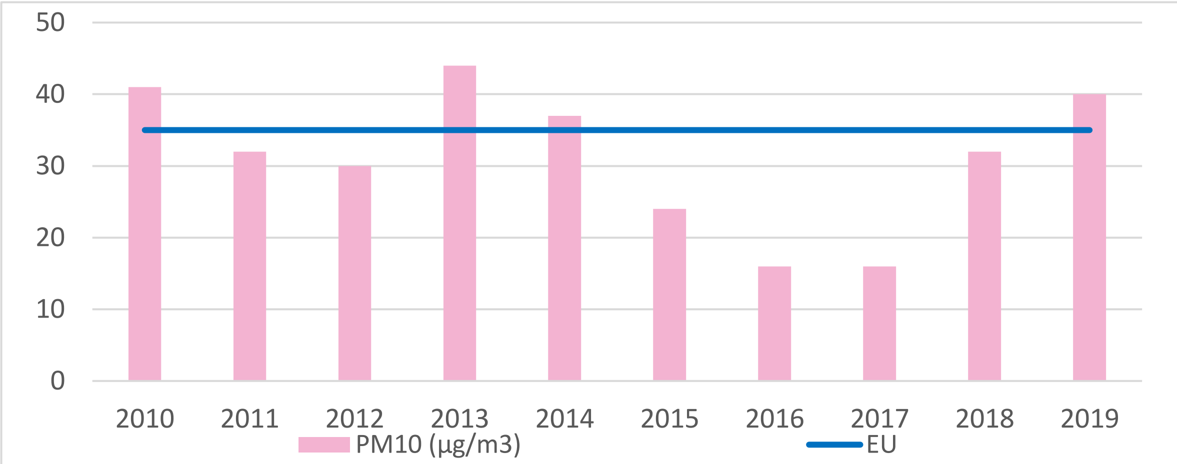

Chart 5: Number of days the daily limit value of PM_{10} is exceeded (50 µg / m^3) in Petrašiūnai station (Kaunas)
Source: Aplinkos apsaugos agentūra (25/02/2020 Air Quality Assessment Unit)

In that sense, *Chart 5* shows the different registered values in Petrašiūnai for the last 10 years. Although it is true that during the years 2013 – 2017 there is a significant decrease in the number of exceeded days, the last three years are following the same tendency experimented in the average annual concentration. Besides, the most negative point is the breach of EU legal regulations. We assume/it is assumed? that the major part of these days is registered in the warm period when the precipitations are less often and exist a more anticyclonic climate.

- **$PM_{2,5}$**

They are very small particles in the air of 2.5 microns or less in diameter. Due to its reduced measure, they can have a deeper impact on human health. They are 100% breathable since they travel deep into the lungs, penetrating the respiratory system and depositing in the pulmonary alveoli, they can even reach the bloodstream. This type of particulate are the ones more related to traffic affectations.

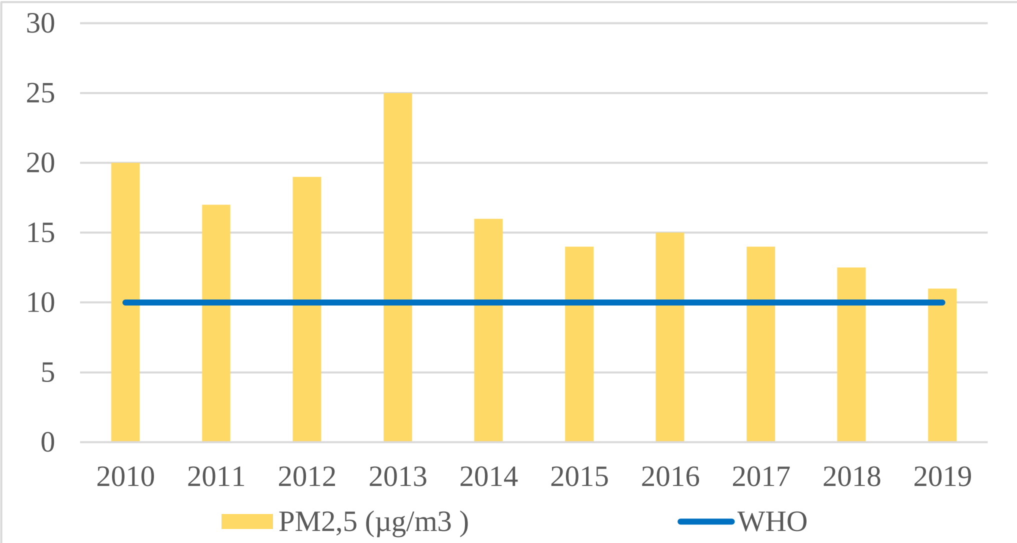

Chart 6: Average annual concentration $PM_{2,5}$ concentration Petrašiūnai (Kaunas)
Source: Aplinkos apsaugos agentūra (25/02/2020 Air Quality Assessment Unit)

As well as in the case of PM_{10}, the $PM_{2,5}$ levels are higher than the estimates of the World Health Organization. Nevertheless, this time it may be seen that there is a favorable tendency in reducing

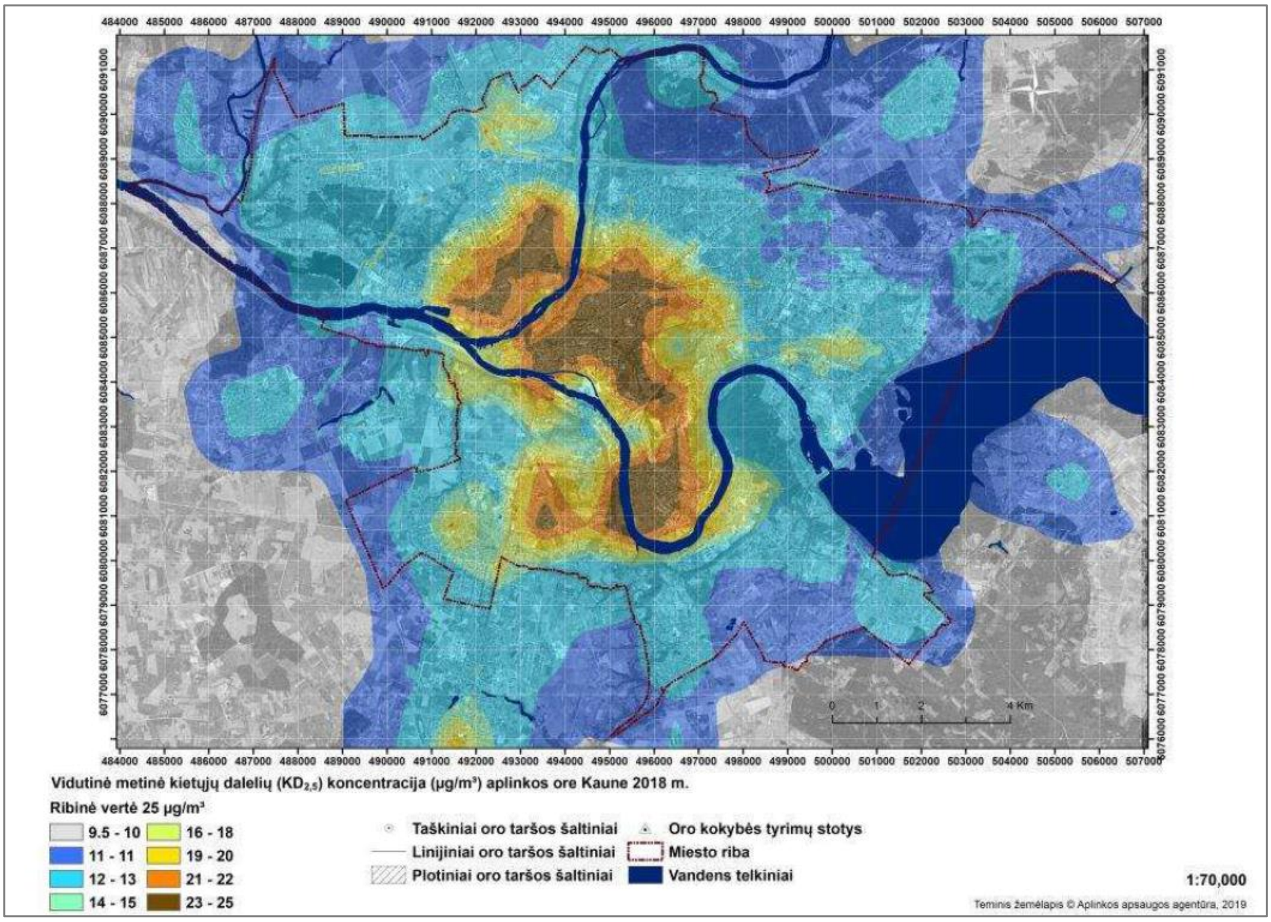

Figure 2: Average annual concentration of PM2.5 (µg / m3) in Kaunas (according to ADMS-Urban model)
Source: Oro Kokybe Lietuvoje 2018, Aplinkos Apsaugos Agentura, Vilnius 2019.

its concentration. During the last 7 years, due to the improvement of combustion engines and the improvement of infrastructures in the city, it has been an important constant reduction.

Also, the modeling results show that the highest concentration of $PM_{2.5}$ in Kaunas should be in densely built-up areas and detached houses (*Figure 2*). The 2018 measurement data show that the average annual concentration of $PM_{2.5}$ in Kaunas reaches 12 μg/m^3, and according to modeling results in some in urban areas, it can reach 23-25 μg/m^3.

One interesting discovery when comparing the results given by *Figure 2* and *Chart 6* is the important difference that exists between the data from the Petrašiūnai air measurement station and the study from Aplinkos Apsaugos Agentura. With this, it is not risky to affirm that the air quality measurement station is outside the areas where the highest pollution values are registered.

1.1.2. Carbon monoxide CO

Carbon monoxide is a colorless and highly toxic gas. It can cause death if breathed at high levels. It is produced by the poor combustion of substances such as gas, gasoline, kerosene, coal, oil, tobacco, or wood. For instance, the engine start of vehicles generates big quantities of CO. For this reason, there has been a lot of effort put towards investigating and developing new processes and catalyzers to minimize the residual production of CO during combustion.

The air pollution originated by carbon monoxide is assessed by comparing an 8-hour moving average with the limit value established for the same period. Fortunately, the registered values in Petrašiūnai measuring station show a good quality of levels according to the World Health Organisation 2005 Guidelines.

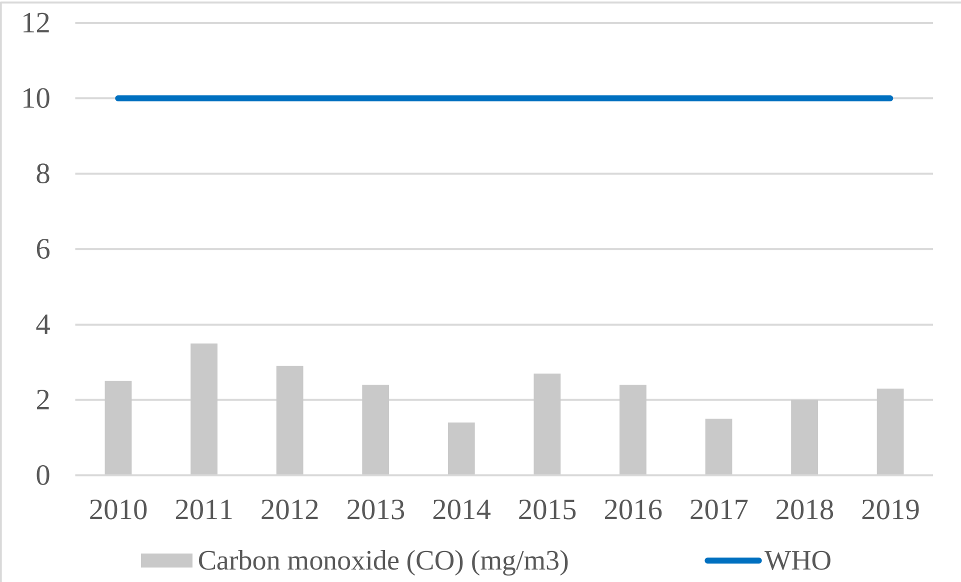

Chart 7: Maximum 8-hour concentration CO in Petrašiūnai station (Kaunas)
Source: Aplinkos apsaugos agentūra (25/02/2020 Air Quality Assessment Unit)

1.1.3. Nitrogen dioxide NO_2

Nitrogen dioxide is a nasty-smelling gas that is in its 1% formed naturally in the atmosphere by lightning and some are produced by plants, soil, and water. However, the major source of nitrogen dioxide formation is the burning of the following fossil fuels: coal, oil, and gas. Most of the nitrogen dioxide found in urban areas comes from motor vehicle exhaust (about 80%). Other sources of nitrogen dioxide are petrol and metal refining, electricity generation from coal-fired power stations, other manufacturing industries, and food processing.

"The main effect of breathing in raised levels of nitrogen dioxide is the increased likelihood of respiratory problems. Nitrogen dioxide inflames the lining of the lungs, and it can reduce immunity to lung infections. This can cause problems such as wheezing, coughing, colds, flu, and bronchitis." (Department of the Environment and Heritage (Australia), 2005).

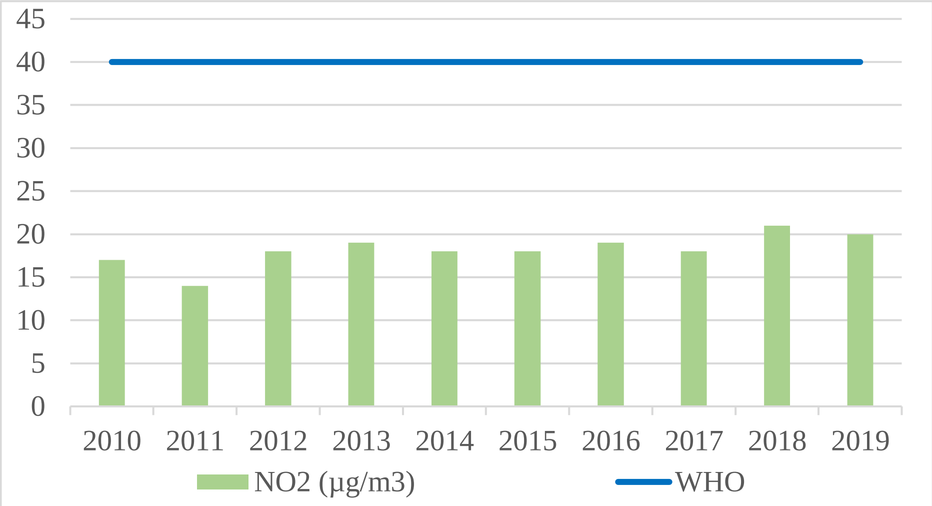

Chart 8: Average annual concentration NO2 in Petrašiūnai station (Kaunas)
Source: Aplinkos apsaugos agentūra (25/02/2020 Air Quality Assessment Unit)

In the case of NO_2 the levels of average annual concentration are low and in accordance with the World Health Organization (see *Chart 8*). As may be seen, the values have been very contended during the last 10 years, and it doesn't seem to be a very clear increasing tendency.

Regarding NO_2 and CO concentration levels, it could be possible that the levels keep being very low due to two presumably assumptions:

- The high precipitation registers that Kaunas city has compared to other cities.
- These gasses are found in the air, but as they are not particulates, once the air is clean, they can't be reintroduced to the air through the elevated pollution.

1.2. Traffic congestion

Congestion is a phenomenon that occurs when the demand on a road is higher than the maximum flow capacity that the road can afford. The consequence is the formation of queues due to the bottleneck that is formed. Sometimes, traffic congestion also occurs when the capacity of the road is reduced for inconveniences such as a closed lane, accidents, police controls, or incorrectly parked cars. In this case, the supply for circulating it is reduced at a lower maximum flow than the demand.

According to experts, congestion occurs because roads are free to use. This fact is the central concept for understanding traffic congestion. In other words, it's been experienced with many different products that went these products are priced, consume reduces, whereas when underpriced, they are prone to shortages. This phenomenon is easily understandable when thinking about toll roads. When a toll is installed on a highway, automatically the traffic on it decreases.

In general, traffic congestion is not a major problem in Kaunas. Due to its low population density, Kaunas is not experimenting with constant traffic problems. As may be seen in *Chart 9*, Lithuania is one of the best European countries in terms of traffic congestion. Nevertheless, maybe traffic is not a generalized problem in Lithuania or even in Kaunas, but this doesn't mean that in some concrete urban areas of the city center of Kaunas could be happening congestion issues. As it has been said, traffic congestion can also be created on account of disruptions in the normal capacity flow of an urban road. Freight transport vehicles could be an example, as due to its big dimensions, they are often susceptible to create traffic jams at the time of loading or unloading. Also, the intensive use of urban roads by a large number of cargo vehicles can create delays and a slowdown in urban traffic.

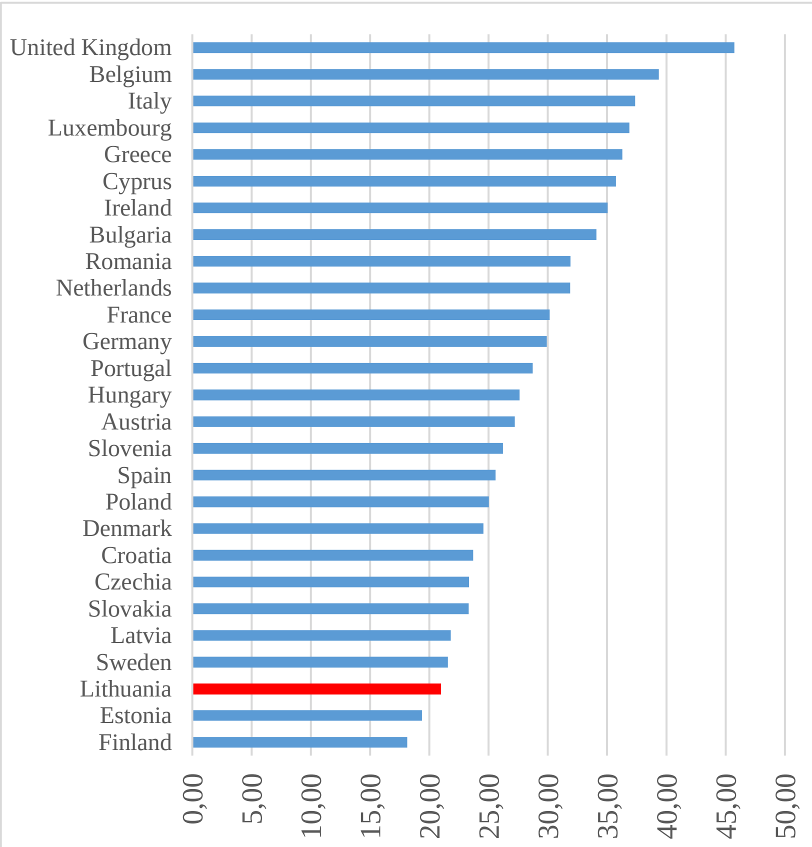

Chart 9: Hours spent in road congestion annually.
Source: JRC, TomTom 2017

Much has been written about traffic flow theories, pricing, and traffic congestion. However, this section, focus on the direct consequences of traffic congestion and not its origin. The different consequences of traffic congestion have been classified as follows:

- **Economic**
  Traffic congestion generates delays in companies' shippings and more expenditures on salaries and fuel. "Congestion in the EU is often located in and around urban areas and costs nearly EUR 100 billion, or 1 % of the EU's GDP, annually." (Christidis, 2012)

  As Matthias Sweet points in his article *"Does traffic congestion slow the economy?",* it is important for countries' development to keep contained congestion levels. As the research suggests, “congestion slows metropolitan growth, inhibits agglomeration economies, and shapes economic geographies”. (Sweet, 2011)

- **Environmental**

  Congested roads provoke that cars circulate during more time inside urban areas. That means that for a longer time, vehicles are going to be emitting pollutants to the air. Also, the traffic jams originate more gas emissions derivated from inefficient conductions with more start and stop.

- **Social**

  As may be seen in *Chart 9*, during 2017, Lithuanian citizens spend an approximate average of 21 hours every year stuck in traffic jams. Despite not being very high value in comparison to the other countries, it is important to control its level to avoid the worst future consequences.

  Traffic congestion is an element that can hinder the development of a normal day, generating delays, and creating unexpected drawbacks. Time wasted and the frustration generated on daily traffic congestion is an issue that can have an important impact on citizens' live quality (Ghazali, 2019).

1.3. Noise pollution

The European Environment Agency warns that noise pollution is a major environmental health concern in Europe, where at least a 20% of the EU population lives in areas where traffic noise levels are harmful to health. (European Environment Agency, Nov 2019) The adverse effects on those exposed to noise pollution include threats to the well-being of human populations, the deteriorating health and distribution of wildlife on land and in the sea, the decreased abilities of our children to learn properly at school and the high economic price society must pay as a result.

Transport is the main important source of noise pollution in urban areas. Concretely, road transport is commonly the major contributor to this pollution. Road traffic noise is caused by the combination of rolling noise and propulsion noise. Rolling noise is the interaction between the vehicle tyre and the road surface, and it is estimated that above a speed of 40km per hour for most of the cars, and above 70km per hour for trucks, it constitutes the main source of road traffic noise. (Van Blokland and Peeters, 2009)

In the WHO guidelines for noise pollution classified traffic noise, including road, rail, and air traffic as the second most important cause of ill health in western Europe, being air pollution the first one, caused by PM. Noise impact depends on its level. Along these lines, it is estimated that 14,1 million adults are severely annoyed by environmental noise, 5,9 million adults are highly sleep disturbed, 69 000 hospital admissions and 15 900 cases of premature mortality occur annually, all of them due to environmental noise (European Commission, 30/03/2017). WHO recommendations in terms of noise levels are:

“For average noise exposure, reducing noise levels produced by road traffic below 53 decibels (dB) L_{den}[2], as road traffic noise above this level is associated with adverse health effects. For night noise

[2] L_{den}: Day-evening-night-weighted sound pressure level as defined in section 3.6.4 of ISO 1996-1:2016

exposure, reducing noise levels produced by road traffic during night time below 45 db L_{night}[3], as night-time road traffic noise above this level is associated with adverse effects on sleep." (World Health Organization, 2018)

The set limit in the Environmental Noise Directive is to keep noise behind 55 dB. In Lithuania, as it may be seen in Table 4, the percentage of people exposed to noises that are over the limit is up to 28,2%. This represents that around 790.000 people are living exposed to these harmful levels. It draws attention to the percentage of people who are exposed to high noise levels due to road traffic with 26,3%. It means that around 735.000 people, almost 2,5 times the population of Kaunas, is affected by road noise. It is also noted that for the noise originated in road transport, Lithuania is considerably higher than the average of the EEA-33[4].

Table 4: Percentage of country population exposed to $L_{den} \geq 55$ dB in areas covered under the END 2017[5]
Source: Environmental noise in Europe 2020, European Environment Agency, Nov 2019.

	Inside urban areas				**Outside urban areas**		
	Road	Rail	Air	Industry	Road	Rail	Air
Lithuania	26,3	0,4	0,4	0,3	0,8	0,0	-
EEA-33	15,5	2,0	0,6	0,2	5,9	2,1	0,2

1.4. Vehicles fleet

Countries like Lithuania are experiencing problems with the renewal of their vehicle fleets. In times where air pollution in cities is becoming, day to day, a more serious problem, administrations might need to accelerate this renewal. As may be seen in Table 2, old vehicles have lower restrictions at the time of polluting. For example, a vehicle 10 years older can pollute 2 times more than a new one.

Furthermore, in addition to the old vehicles issue, it also exists a diesel majority. Diesel vehicles are the main cause of $PM_{2.5}$ and PM_{10} air pollution, that as it has been said previously, have very harmful

Figure 3: N1 and N2 respectively, freight vehicles used in urban freight distribution.
Source: Dpd Group and Amazon.

[3] L_{night}: Equivalent continuous sound pressure level when the reference time interval is the night

[4] EEA-33: They are the 33 European countries (not all from UE) that took part in the EEA.
[5] END 2017: Environmental Noise Directive from 2017 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52017DC0151&from=en

effects on human health. In Lithuania, which is the only baltic country whose rate of diesel is higher than petrol vehicles, it exists 61,35% of diesel vehicles (State Enterprise Regitra, 2020).

Lithuania is the country from the Baltic states that has the largest and oldest vehicle fleet circulating in its roads. On one hand, it has the largest vehicle fleet due to its largest population. On the other hand, there is an important tendency of importing used cars, 32.500 in 2013, that represents 3,5 times more importations than Latvia and 5 times more importations than in Estonia (Daukšas, 2014).

The most common vehicles used for urban freight distribution are light vans with a maximum authorized mass of less than 3.500 kg. Nowadays, it is easy to see these vehicles daily circulating through all European capitals. Other freight vehicles that are often used but to a lesser extent are the ones that have a maximum authorized mass between 3.500 kg and 12.000 kg. These two types of vehicles are classified in the regulations as N1 and N2 respectively.

In freight vehicles, it is more common to find old and diesel vehicles. Currently, the rate of diesel vehicles in the city of Kaunas is about 97% for N1 category and about 92% for N2. (State Enterprise Regitra, 2020). As may be seen in *Chart 10* the number of diesel vehicles far outweighs the rest. Also, it is noticeable the few market penetration that electric or green vehicles are having. One reason for that is that electric vehicles, because of their autonomy and capacities, are still not able to fully fulfill business needs as diesel does.

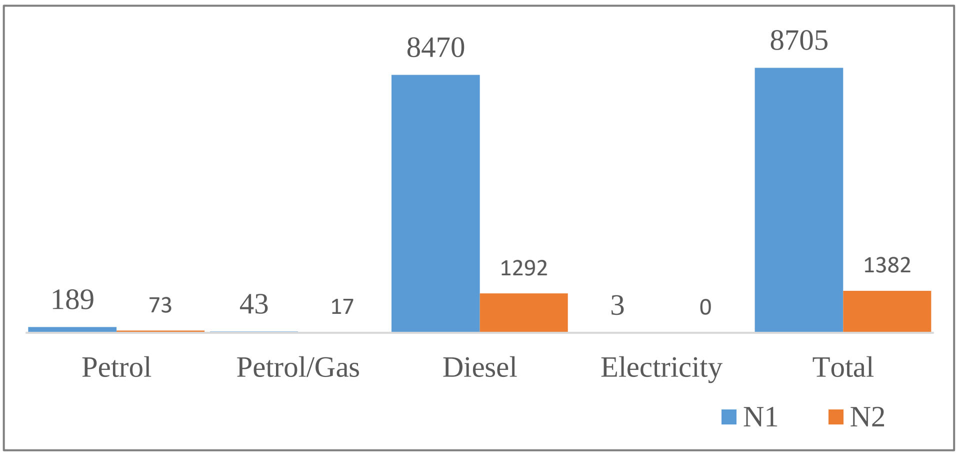

Chart 10: N1 and N2 freight vehicle fleet in the city of Kaunas
Source: Lithuanian State Enterprise Regitra (2020).

To provide a wider vision of the problem, it is wanted to show also the rate of passenger cars available in the city of Kaunas. Besides, despite these vehicles, categorized as M1, are not thought for freight transport, it has been observed that its use has become very popular for food delivery. With the emergence of mobile applications (Bolt food, Wolt, Lekste…) that offer food delivery services, a lot of restaurants are using these channels to arrive to more clients. As a consequence of this, a lot of cars are taking part in the urban distribution of goods.

Again, but in less proportion, the diesel represents the higher rate of vehicles. Unlike freight vehicles, it exists a deeper market penetration in the sector of greener vehicles, with 8.92% of the vehicles if we consider hybrid and electric vehicles. Nevertheless, these numbers are far to be a favorable scenario for a change in the city's air pollution, the need for a modal transfer towards sustainable modes of transport is noticeable.

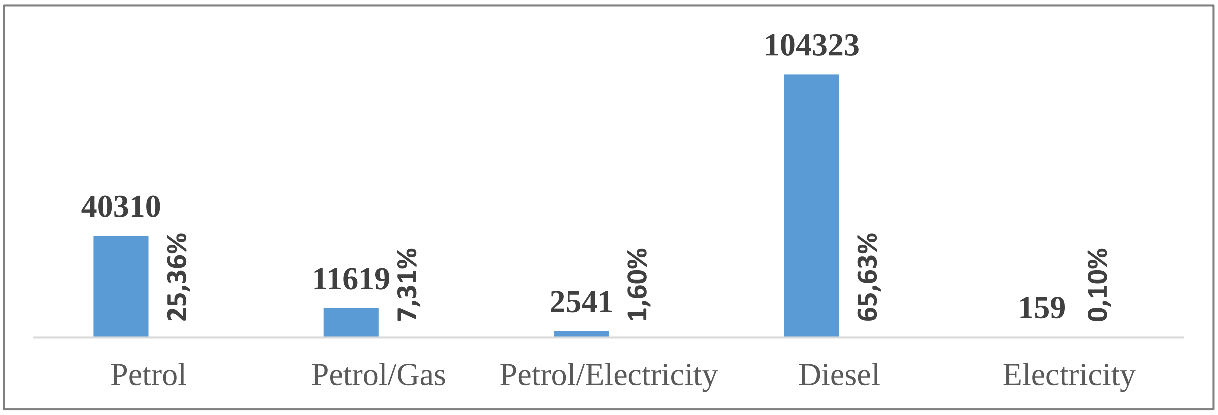

Chart 11: Number and share of Car fleet (M1) by fuel type in the city of Kaunas.
Source: Lithuanian State Enterprise Regitra (2020).

2. Project Objectives

This project wants to be a step forward to the improvement of the urban freight distribution in the city of Kaunas. This project is always going to put the focus on sustainable development of mobility and economic activities. The project horizon is that no progress is achieved without sustainable solutions for cities and thus, the aim of this project is to reach a sustainable solution for the problems caused by urban freight distribution. However, at the same time, it is pursued the development and efficient increase of the sector.

To reach sustainability, as it has been seen previously, Kaunas has to face the problems that are putting the city development at risk. This project aims to set some regulations and facilities to the urban freight distribution activities to:

- Reduce greenhouse gas emissions
- Reduce the urban freight distribution impact on social welfare
- Establish more sustainable and efficient logistics models
- Increase competitiveness and attractiveness of the city's business environment

On the other hand, to achieve these objectives, it is going to characterize the urban distribution sector of Kaunas. To launch suitable measures for the Kaunas urban distribution landscape some questions should be answered; What are the agents involved in the urban distribution of goods? What are the areas with the greatest mobility of goods? What sensitive areas should we protect in the city? What are other cities doing to face this challenge?

These and more questions are going to be solved in the following chapters. On one hand, by identifying the main stakeholders and variables that influence urban freight distribution, it will be a better knowledge of the functioning and relations that take place in the sector. On the other hand, identifying what are doing those cities that are facing the same issues than Kaunas will provide to the project the experience to implement a successful solution.

Once the urban freight distribution scenario will be clear, the project aims to develop a conjunct of measures that will try to reach a more sustainable scenario in Kaunas' future. These measures are the ultimate goal of this project, as it has been said at the beginning of this chapter, the project aims to be a guideline for the sustainable development of Kaunas.

2.1. Sustainability

"Sustainability, the long-term viability of a community, set of social institutions, or societal practice. In general, sustainability is understood as a form of intergenerational ethics in which the environmental and economic actions taken by present persons do not diminish the opportunities of future persons to enjoy similar levels of wealth, utility, or welfare." (Meadowcroft, 2020)

Just with long-term thinking, it will be possible to establish an urban freight transport planning respectful with the environment. Sustainability is presented as an alternative to short-term, myopic, and wasteful behaviors. The world is now starting to suffer the effects of years and years of greenhouse gas emissions. While greenhouse gas emissions remain, humanity is compromising the next generations' future. For this reason, sustainability has to be a mandatory request in future countries' strategic plans. It can serve as a standard against which existing institutions are to be judged and as an objective toward which society should move.

The guiding criterion for changing the production, energy, and mobility model is not cost/profit in the realization of the private profits of producers' operators, issuers, or receivers. The guiding criterion is to optimize the welfare of the social majority, which implies to solve the system of equations composed of ecological sustainability while respecting the balances of the biosphere – the very foundation of human life – the development of the productive economy – to build a solidary city and society. This means that the optics to address the urban freight distribution planning must be on the prism of the general good, of the common good (M. Ferri, 2012).

As the definition states, sustainability is the integration of at least 3 concepts; environmental considerations, social welfare, and economic development. Regarding the project, at the time of developing the different measures, it has been tried to have the holistic approach of these 3 concepts as an indispensable requirement to success on the obtained results. As may be seen in Figure 4, from each concept it will be analyzed some different aspects like the ones represented.

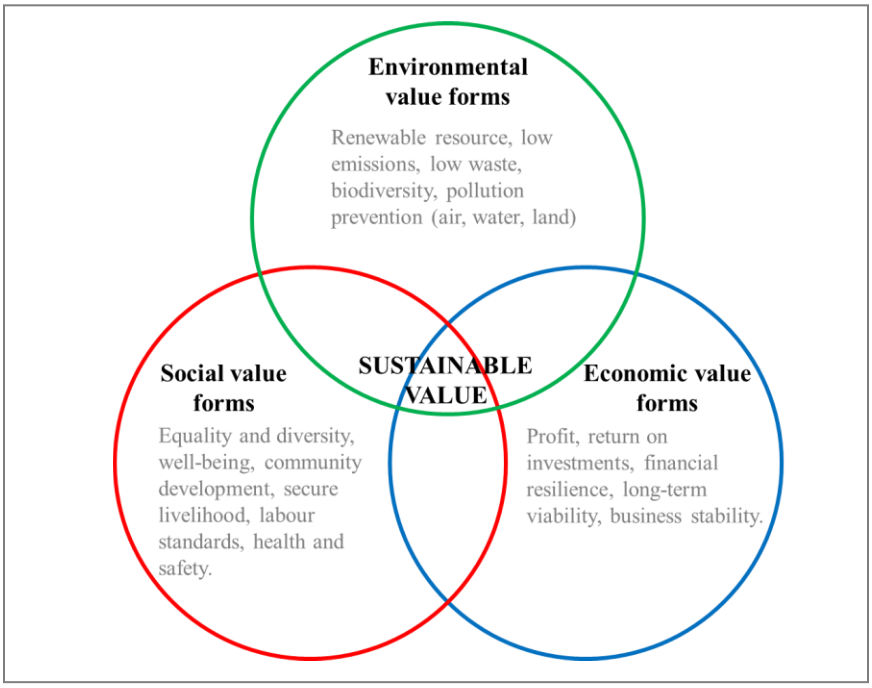

Figure 4: Explanation of the three dimensions of sustainability
Source: Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., A. Silva, E., Y. Barlow, C., (2017) Business Model Innovation for Sustainability. Institute for Manufacturing Department of Engineering, University of Cambridge, UK.

3. Characterization of Kaunas Freight Distribution

Urban freight distribution has not been traditionally in the priority list of municipalities. The main difficulty faced with its characterization and diagnosis is the lack of updated, proven, and stable information of these flows. Systematically having urban freight mobility data would allow to improve the identification of problems and determine the real contribution of this segment to various externalities concerning the total road traffic. Moreover, this data could facilitate the generation of mobility planning solutions and the evaluation of the results when implementing solutions.

However, knowing that the data available in terms of urban freight distribution is limited, this chapter is going to describe the urban freight distribution scenario that involves the city of Kaunas. Understanding the Kaunas transport sector and the conjunct of variables and stakeholders that are involved in the urban distribution would allow taking suitable decisions for the sector.

In short, after recognizing the problematics that happen in Kaunas in chapter 1, the next step is to make a characterization of the Kaunas urban freight distribution sector to understand its weight and its role in the city.

3.1. Introduction

Kaunas is an emerging city in northern Europe. As will be seen below, its convenient geographical location, well-developed transport infrastructure, good transport connections with major Lithuanian cities, and exceptional perspectives for the future development of infrastructures. Therefore, the prospects of Kaunas becoming an important Eastern European crossroad of the road, rail, water, and air transport are realistic.

3.1.1. Location

Kaunas is in a strategic location in the center of Lithuania. Located only 100 km from Vilnius and 212 km from the country's major seaport Klaipeda. Kaunas is also located in the confluence of rivers Neris and Nemunas which give the city a potential on the development of inland waterway transport.

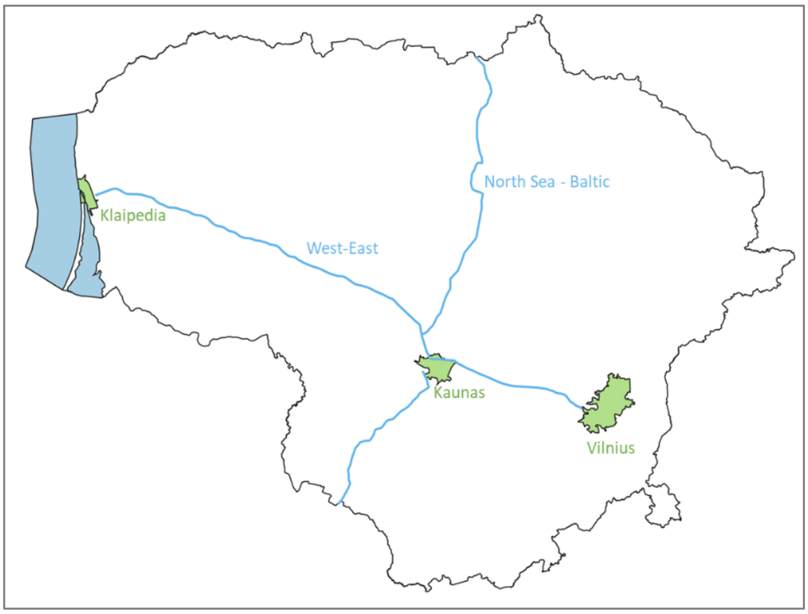

Figure 5: Lithuanian TEN-T corridors.
Source: Own elaboration according to data from OpenStreetMap.

A major part of the transport in Kaunas depends on road traffic. Kaunas is located at the crossroads of the country's two strategical corridors; the West and East corridor that connects Vilnius with the ice-free Klaipeda Seaport and the Via Baltica. Both corridors are part of the North Sea-Baltic corridor that is integrated into the Trans-European Transport Networks also known as TEN-T corridors.

The TEN-T core network road corridor North Sea-Baltic in the territory of Lithuania consists of four sections. These are Riga-Kaunas, Vilnius-Kaunas, Kaunas-Klaipeda, and Kaunas-Warsaw. All the mentioned sections have passenger and cargo transportation. There are public logistics centers next to these sections that connect road and rail networks.

The section Riga - Kaunas extends in a north-south direction and is international highway E67, which connects Helsinki and Prague and it's the so-called Via Baltica. Its section from Kaunas to Sitkūnai (about 20 km) of the motorway (Al) has two lanes in both directions and other parts of A8, A17, and A10 have one lane in both directions. (European Commission, Dec. 2014)

3.1.2. Population

Kaunas is the second-largest Lithuanian city with an urban population of 286.754 inhabitants. The population density of Kaunas is the highest in the country 1.827,8 inhabitants-km^2. However, as it may be seen in Table 5: Population Density, the population density in Lithuanian countries is very low compared to its neighbors' capitals in Poland and Latvia. Table 5 is also showing the city with the highest population density in all of Europe, Hospitalet de Llobregat, a dormitory city next to Barcelona.

Table 5: Population Density
Source: Eurostat (2019). https://ec.europa.eu/eurostat/web/nuts/local-administrative-units

Country	**City**	**Population (inhabitants)**	**Surface (km^2)**	**Density (inhabitants/km^2)**
Spain	L'Hospitalet de Llobregat	264.923	13,62	19.450,80
Poland	Warszawa	1.777.972	517,24	3.437,42
Latvia	Rīga	632.614	303,78	2.082,47
Lithuania	Kaunas	286.754	156,88	1.827,80
Lithuania	Panevėžys	87.139	50,11	1.738,87
Lithuania	Klaipėda	147.892	98,05	1.508,36
Lithuania	Vilnius	552.131	400,45	1.378,77

Thus, after this comparison, we can state that the population density of Kaunas, despite being the highest in Lithuania, is low. This fact causes that at the time of purchasing goods, demand is very spread in all the Kaunas surface (see Figure 6).

However, by observing *Figure 6,* it may be easily identified 3 high-density areas. These areas are located in the north of the city where the population density is higher. Also, it is observed how these areas are next to the 3 main transit routes: Baltų, Šiaurės, and Pramonės ir Savanorių ave. The involved neighborhoods: Dainava, Eiguliai, Milikoniai, and Sand, are dominated by apartment buildings that concentrate a lot of people. Here the population density reaches 20.000–27.500 inhabitants / km^2. But such high density is typical of only a small part of the urban area, elsewhere the density does not exceed 2.500-5.000 habitants / km^2.

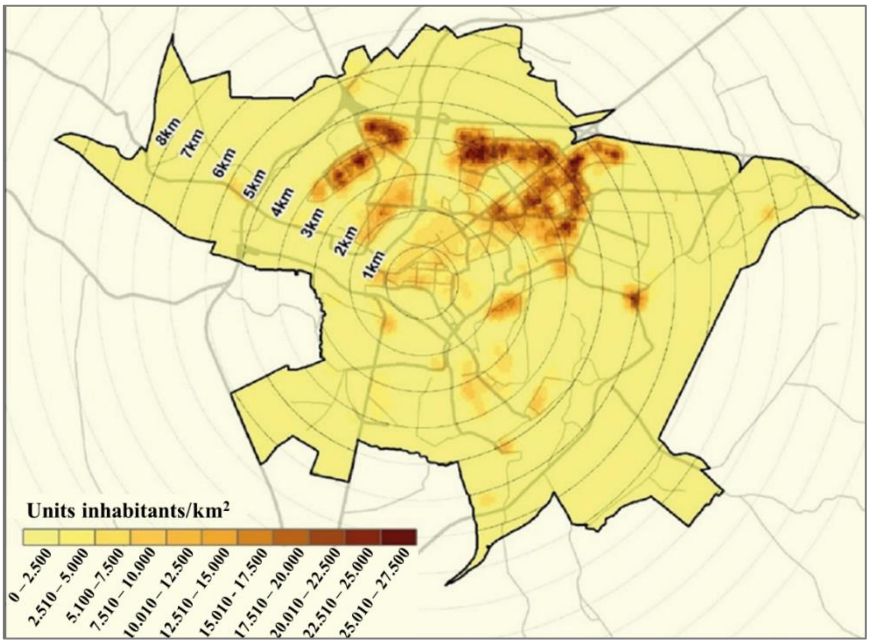

Figure 6: Kaunas population density (Households)
Source: Dumbliauskas, V., Barauskas, A., Kauno miesto gyventojų ir darbo vietų tankio analizė transportiniu požiūriu. Vilniaus Gedimino Technikos Universitetas (2015).

On the other hand, *Figure 7* shows how population density spreads during the working hours. As may be seen, the concentration is focused on the city center of Kaunas. Evidently, it is in the center where most of the companies and office buildings are located. The population density in this zone goes from 20.000 inhabitants/km^2 up to 25.000 inhabitants/km^2. We can also find densities around 5000 inhabitants/km^2 to 7.500 inhabitants/km^2 in the areas where in the previous *Figure 6* where found the highest household densities.

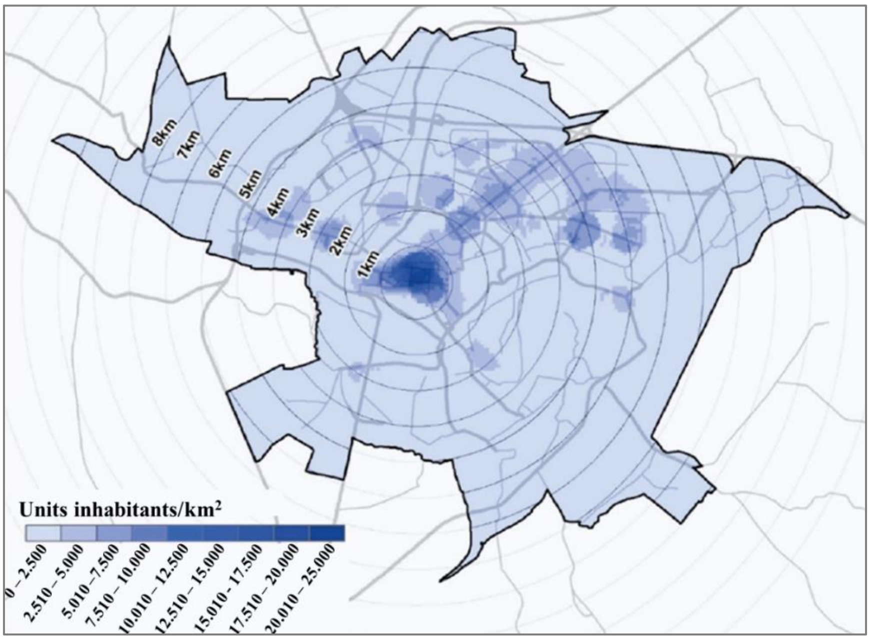

Figure 7: Workplace Kaunas population density.
Source: Dumbliauskas, V., Barauskas, A., Kauno miesto gyventojų ir darbo vietų tankio analizė transportiniu požiūriu. Vilniaus Gedimino Technikos Universitetas (2015).

3.1.3. Economic weight

Kaunas is the second most significant city in Lithuania. To understand Kaunas' relevance in the Lithuanian industrial and business landscape, it is important to notice that it is an important economic motor for Lithuania with a 20,7% of the GDP (see Table 6). While the capital, Vilnius, represents the most important city in the country, Kaunas is the strongest commercial pole for the western and central regions.

Table 6: GDP at current prices

Source: Lithuanian Statistics Portal (https://osp.stat.gov.lt/)

	2018	
	EUR million	**%**
Republic of Lithuania	45.264,40	100,0%
Vilnius county	18.907,70	41,8%
Kaunas county	9.367,20	20,7%
Klaipėda county	4.941,00	10,9%

It is important to highlight that Kaunas and Vilnius, are the two cities that have been growing at the highest rates than the rest of the country. Even, it may be seen in Chart 12, that Kaunas county has been growing for the years 2016 and 2017 at higher rates than Vilnius.

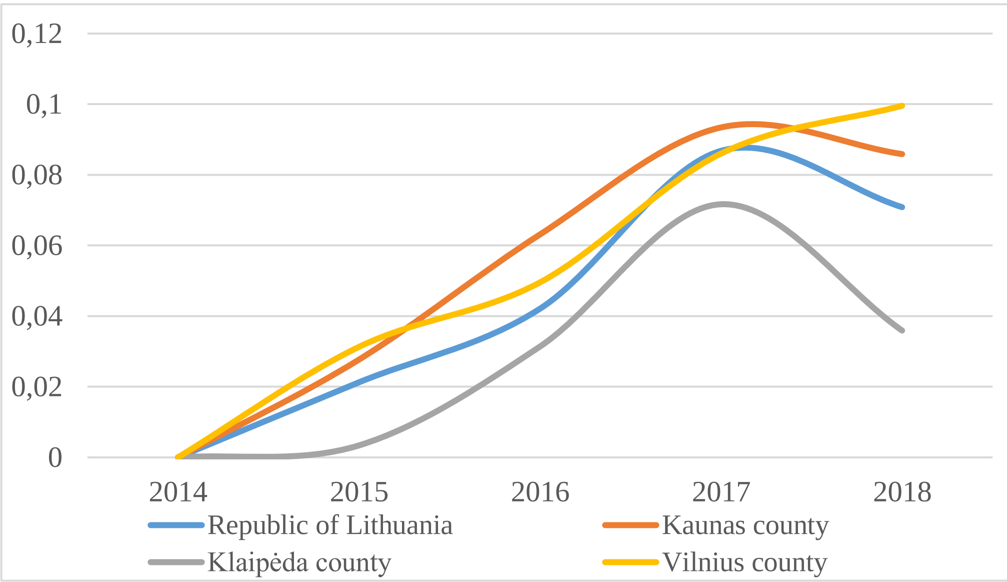

Chart 12: GDP (at current prices) growth rate

Source: Own elaboration according to data from Lithuania Official Statistics Portal.

Logistics and Transport sector in Lithuania represent an important sector for the country. As it has been said before, Lithuania's geographical position is advantageous for transport communications. Lithuania is centrally located between three sizeable markets: Western Europe, the Nordic countries, the Eastern markets of Russia and the Commonwealth of Independent States (CIS). Lithuania has also become one of the EU's primary transport hubs.

Besides, apart from its geographical position, Lithuania has lower labor costs in comparison to its European neighbors and does not only represent an attractive pole for its reduced operating costs but also the general business and living environment are strong values for companies. Therefore, Lithuania has a valued attractiveness at the time of establishing a logistics center (Invest Lithuania, 2015).

The transport sector has special significance in Lithuania, which is the leading EU country in terms of the number of employees working in this economic sector. Moreover, it happens the same with the share of GDP created by land transport and transport via pipelines. During the years 2000 to 2016 transport has been the highest contributor to Lithuanian GDP and has represented the highest rate for the different UE countries (see *Figure 8*).

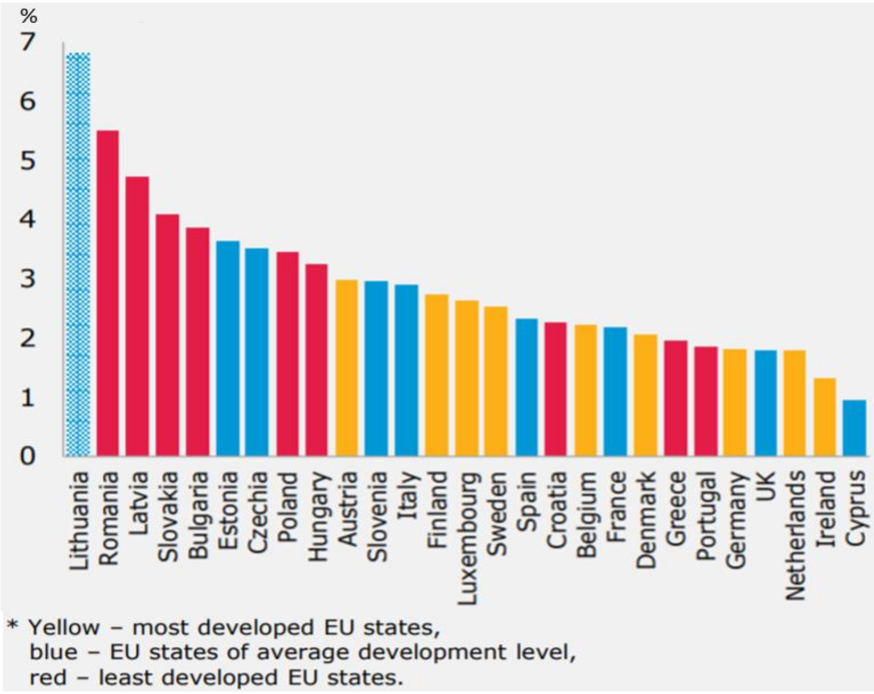

Figure 8: Share of GDP created by land transport and transport via pipelines (2000-2016, at current prices).
Source: Lithuanian Economic Review. Lietuvas Bankas (Sep. 2019).

Another interesting point of view is analyzing the share of tangible investment. During the years 2014 to 2016 the tangible investment for the sector in Lithuania, on average, was about 14,2% of total business investment (excluding financial and insurance activities), 9,4% more compared to the EU average (see *Figure 9*). In short, the transport sector is one of the main powers in the Lithuanian economy. It is a strong transport hub in the EU and as it is evident, its performance has a strong clear dependence on EU economic growth and commercial relations.

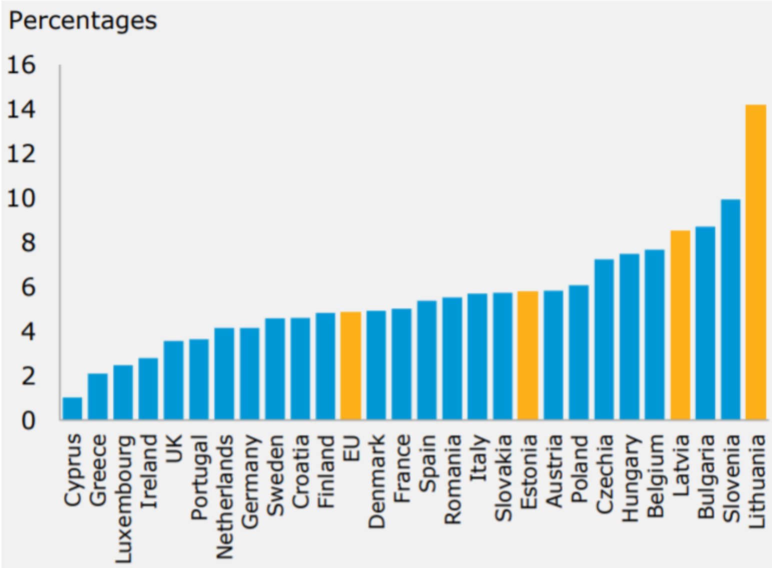

Figure 9: The share of investment in land transport and transport via pipelines in total tangible business investment, average of 2014-2016. Source: Lithuanian Economic Review. Lietuvas Bankas (Sep. 2019).

3.2. Main transport infrastructures

Urban mobility planning requires considering all the different available sources that take place in the Kaunas logistics scenario. This section highlights the different key infrastructures that are necessary to be taken into account to establish suitable urban mobility planning.

It is important to stress that all these infrastructures are public and are managed by companies of the Lithuanian State.

- **Kaunas Airport**

The airport is located just 14 km northeast of the Kaunas city center and 100 km west from the capital Vilnius. Because of its proximity to the city center, the airport represents an attractive for future investors and key infrastructure for the logistics development of the city.

During the year 2019, the airport had an approximate total of 1,160,000 passengers. Which represented a 15% increase from the year 2018, it's the Lithuanian airport that grown more (Lietuvos Oro Uostai, 2019)

The airport is also a freight transport infrastructure, during the year 2019, the number of transported goods was of 3.190 tones. This represents a 6,7% increase from the transported goods in 2018 (Lietuvos Oro Uostai, 2019). The cargo airlines are SprintAir which has Riga, Warsaw-Chopin, and Cologne Airport as the main destinations and Transaviabaltika wich flyes to Minsk.

- **Kaunas Free Economic Zone**

The Free Economic Zone (henceforth FEZ) is a 534 hectares industrial development area that offers land plots supplied with a prepared infrastructure. This industrial complex is composed of 32 foreign and national companies that are developing its economic activity in this environment.

Apart from the economic advantages that the FEZ is offering with the different tax-free policies, the zone has an important logistic attractiveness. Moreover, it offers companies many internal facilities, and a great location of the complex. The FEZ is located near the A6 motorway which is one of the most important highways of Lithuania. Also, it is very near to the TEN-T corridors, as well as to the Kaunas intermodal terminal that is programmed to be finished in 2026.

Also, one of the most important things that give very strong value to the project is its proximity to the Kaunas Airport (3 km). The synergies created between the two infrastructures represent a determining factor for many foreign companies.

- **Kaunas train stations**

The infrastructure will have two differentiated parts; on one hand, it will be the Kaunas Public Logistics Centre (PLC) and on the other hand, to ensure the intermodality of the PLC, it will be built the Intermodal Terminal.

Palemonas in Kaunas District was selected as a convenient location in the country's geographic center. Palemonas' railway infrastructure is well-developed, there is convenient access to the country's main roads (the A1 and A6 motorways and others), nearby are TEN-T 1 and 9 corridors and the Kaunas International Airport, and the seaports of Klaipėda and Kaliningrad are relatively close, opening up routes to Western and Eastern European markets and CIS countries.

The construction project is set in 3 different stages where the Intermodal Logistics Center will be achieving a bigger size. It is estimated that at the end of the whole implementation the project will be reaching a loading volume of 100.000 TEU/year[6].

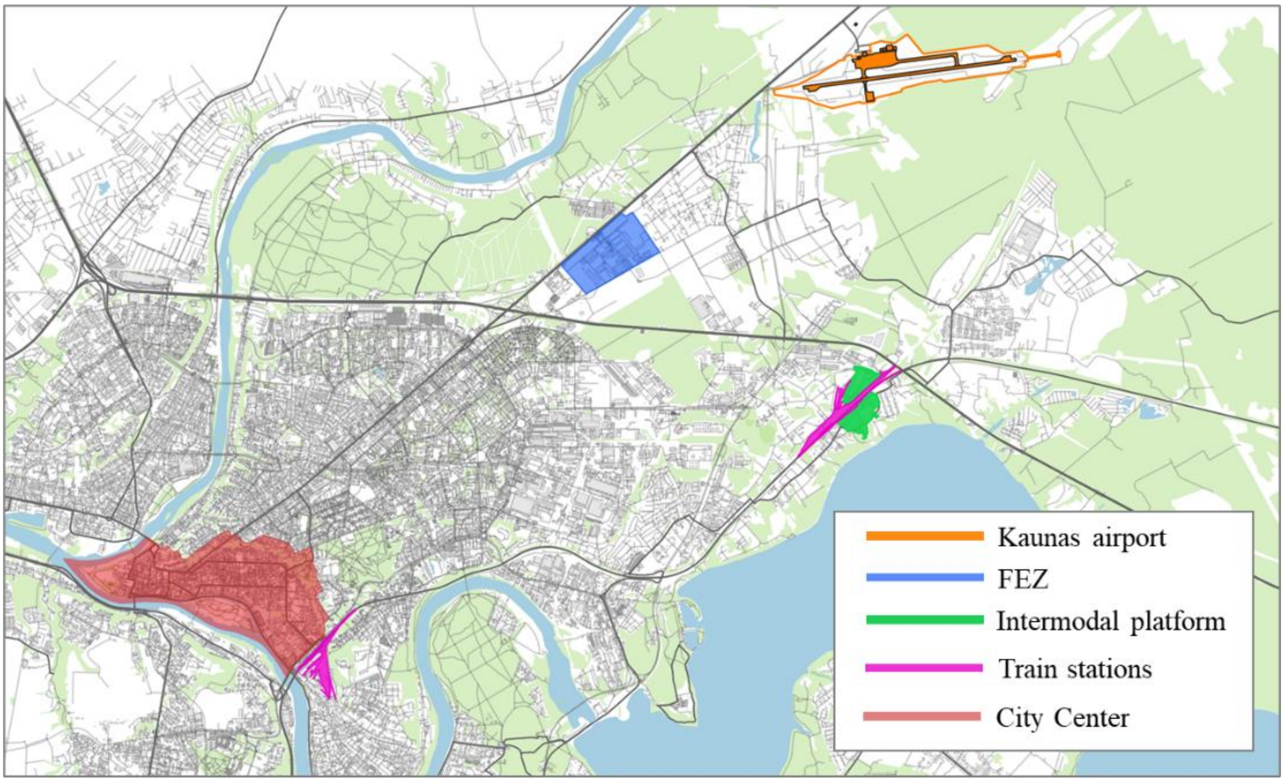

Figure 10: Main logistic interesting infrastructures.
Source: Own elaboration according to data from OpenStreetMap.

[6] **TEU** is from the acronym Twenty-foot Equivalent unit, is an inexact measuring unit for cargo capacity often used to describe the capacity of container ships and container terminals.

3.3. Stakeholders in Urban Freight Distribution

Any Urban Freight Distribution system starts with a demand for goods that are produced elsewhere and must be transported to the demand location. Receivers, logistic service providers, shippers, or regulatory authorities are some of the stakeholders that are interacting in the freight distribution framework. In this section, it is explained the different actors that take part in the Urban Freight Distribution framework, the relationships between them and their specific requirements.

As a summary, it may be seen in Table 7, the number of companies in each category that are operating in Kaunas during this year.

Table 7: Economic Entities in Operation in Kaunas
Source: Own elaboration according to data from Lithuania Official Statistics Portal.

	Economic Entities in operation at the beginning of 2020
Retailers	3,726
Logistics Service Providers	842
Hotel and Catering Industry	521

3.3.1. Demand sectors

Firstly, it is important to state that, as has been seen in section 3.1, demand is affected by the size of the population in a city, as well as the gross domestic product (GDP). Nevertheless, when talking about demand sectors, there is a wide variety of sectors involved with urban freight distribution. Sectors like retailers, offices, restaurants, supermarkets, bookstores, and of course, households just to state some examples.

- **Households/Office distribution and PEC (Parcel, Express, and Courier)**

PEC activity has experimented an important growth since recent years due to the growth of e-commerce. The main element that determines the management of this type of distribution is the short windows of time in which clients set the shipment arrival time. This fact often generates operative inefficiencies at the time of planning routes and as a consequence, it originates higher transit intensity in the cities.

As it has been seen previously in *Figure 6*, the population in Kaunas is spread all around the city. And while this is true, there are also 3 concrete areas in the north of the city where it can be found a noticeable density. With e-commerce increase, households have become a new point where receiving products, and thus a new ending stage of supply chains.

This type of distribution is also common in the office buildings where goods delivery windows are wider and the probability of successfully delivering a product is much higher. In *Figure 7* it is seen how offices are generally concentrated in the city center.

Deliveries in households and offices have a different pattern of behavior in package delivery windows. Households more often set their delivery times at the last hours of the day, out of the working hours. On the other side, offices usually fix their deliveries within the working hours.

The main issue regarding household deliveries is the experienced high rate of failure in each delivery. It is estimated that 23% of deliveries are failed. In most cases, this is because the customer is not at home at the time of shipment. At the same time, household deliveries represent 73% of total e-commerce deliveries, while offices represent 16,8% (RBD Consulting Group, Nov. 2018). Nevertheless, offices often have other sources of deliveries like for example their suppliers, internal mail, prototypes, etc.

- **Retailers**

A retailer is an entity that sells goods such as groceries, clothes, school or office supplies, cars, etc. Kaunas, as every developed city, has a wide network of retailers all over its area. In a similar way to the Hotel and Catering Industry, in the last few years, the sector has consolidated a tendency to do less and more frequent shipments. Retailers are forced to maximize their profits to increase their competitiveness against big retailers and e-commerce online marketplaces (Amazon, Ebay, AliExpress, etc.).

Retailers have traditionally been characterized by having a periodic procurement that would vary its frequency depending on the type of business. To establish some order at the time of classifying different retailers, it has been set the following classification:

- Grocery or alimentary stores may need daily procurement to fulfill their demand needs and also due to its fresh and perennial product.
- Pharmacies have a very strict logistic system where availability is a must and in many occasions, they receive more than one delivery per day.
- Non-perishable product establishments such as kiosks, clothing stores, bookstores, hardware stores or electronics stores, to name a few examples, will set their supplies based on their ability to store hardware and according to their demand. As it has been said previously, in recent years, the tendency has been to provision frequently and in small batches.

Figure 11 shows how retailers are spread along Kaunas city. Three zones stand out because of their notorious concentrations; the center, the Gričiupio neighborhood and, in a fewer measure, the Laisves al. street.

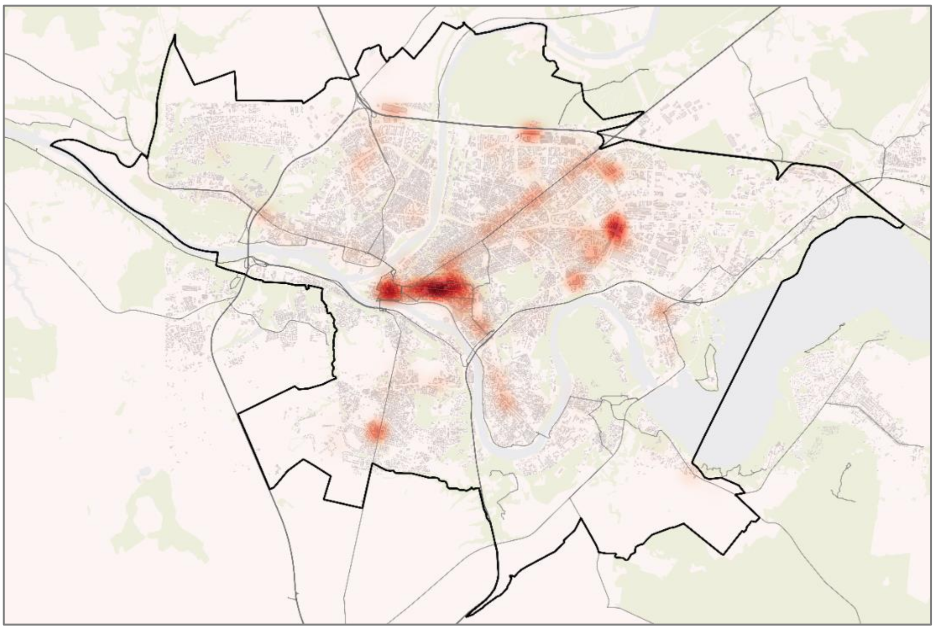

Figure 11: Qualitative spread of retailers in Kaunas.
Source: Own elaboration according to data of OpenStreetMaps.

- **Hotel and Catering Industry**

The Hotel and Catering Industry is the way to refer to Hotels, Restaurants and Caterings establishments. Just in time or Zero Stoc strategies have traditionally been the way this sector has been functioning. In addition, the highly competitive sector has reduced the profit margins and thus the sector looks for a reduction in its operative costs. This behavior has traduced into more frequent and fewer quantity shipments that add increased pressure on urban roads.

On the other hand, in last few years it has appeared a new tendency in food deliver. Restaurants and Catering establishments have become last-mile distributors of goods. The distribution of food is done through last mile service providers or they do it on their own. The demand is located in very concrete times of the day, being its peak between 7.30 pm and 9.30 pm.

As is expected, the main part of the hotels in Kaunas is located in the center, surrounding Laisvės al. and the Old Town area. Kaunas has around 30 Hotels inside the city borders. It happens the same for Restaurants and Catering establishments. However, it is also noticeable a remarkable presence of establishments along Savanorių pr.. *Figure 12* shows qualitatively the concentration of Hotels in the city.

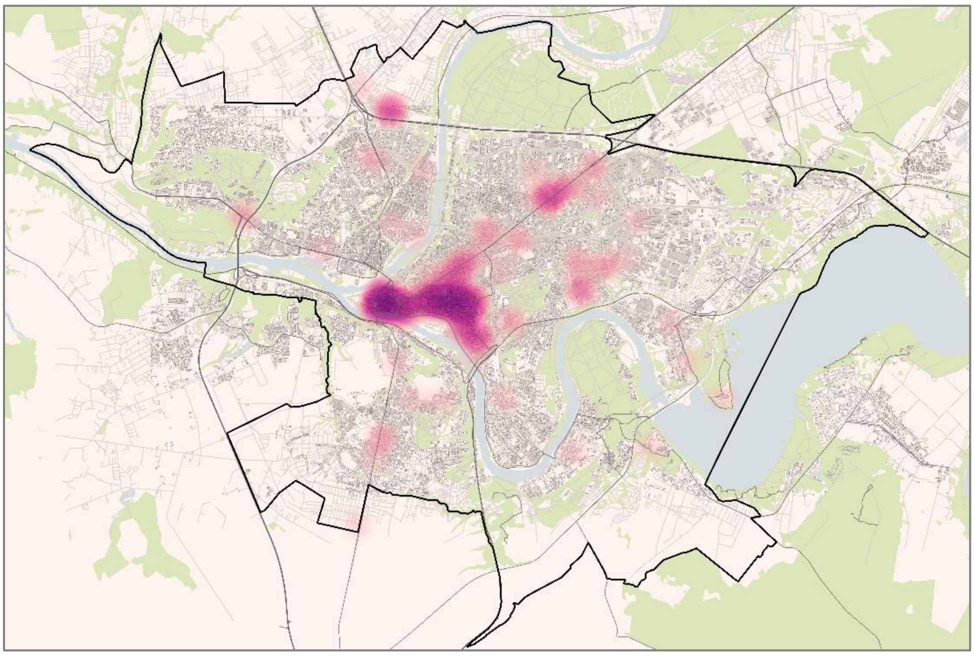

Figure 12: Qualitative spread of Hotel and Catering industry in Kaunas.
Source: Own elaboration according to data of Booking.com and OpenStreetMaps.

- **Supermarkets**

Despite being part of the retail sector, supermarkets and more especially, large establishments, are categorized separately because of its possibility to have a different logistics functioning. Due to its storage capacity and higher volume of sales, supermarkets only require between 1 or 2 daily supplies to supply their shelves. Besides, supermarkets, due to their big dimensions, use to have a loading dock to facilitate loading operations. For this reason, the procurement can be realized through big trucks without being at risk of losing operating profitability.

As it may be seen in *Figure 13* supermarkets are spread along Kaunas, having a special presence in the most populated neighborhoods of the North of the city.

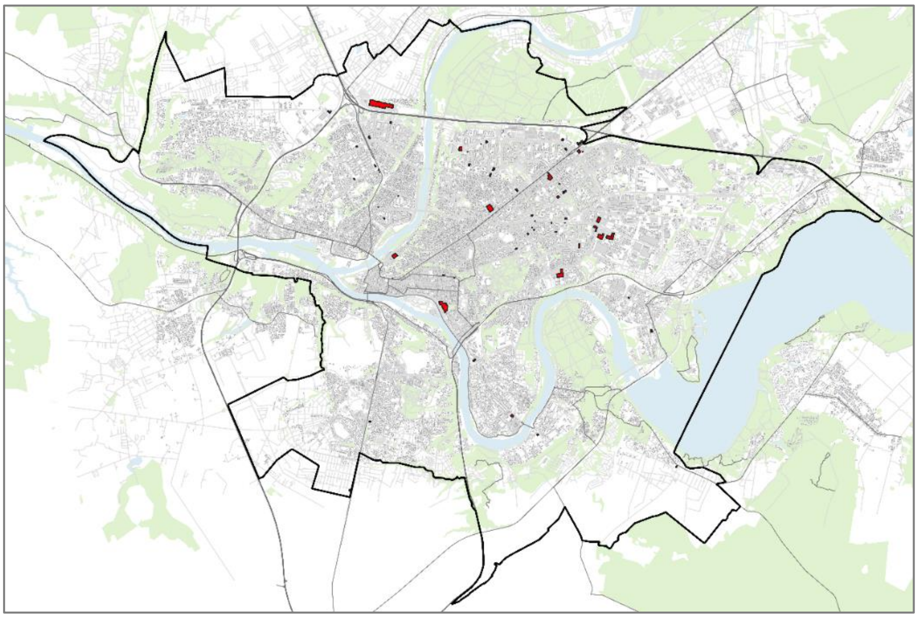

Figure 13: Qualitative spread of supermarkets in Kaunas.
Source: Own elaboration according to data of OpenStreetMaps.

3.3.2. Logistics service providers

The logistics services are realized by what is known as 3PL, Third Party Logistics. These companies offer logistics services in which are included the warehouse, management, and transport of goods. In the last few years, the number of logistics providers has significantly increased, especially inside urban areas where the food and goods delivery has experienced an expansion due to e-commerce increase.

Mainly, in the city of Kaunas, the delivery of products is done with the use of light freight vehicles like vans or even cars. Nevertheless, the use of green vehicles like electric cars or bicycles is slowly growing.

To understand how the movement of goods is, *Figure 14* represents the last mile distribution that supplies the different city receivers. It is seen how deliveries are done from different companies to urban areas. One failed delivery will represent the return of the product to the distribution center and thus a new transport.

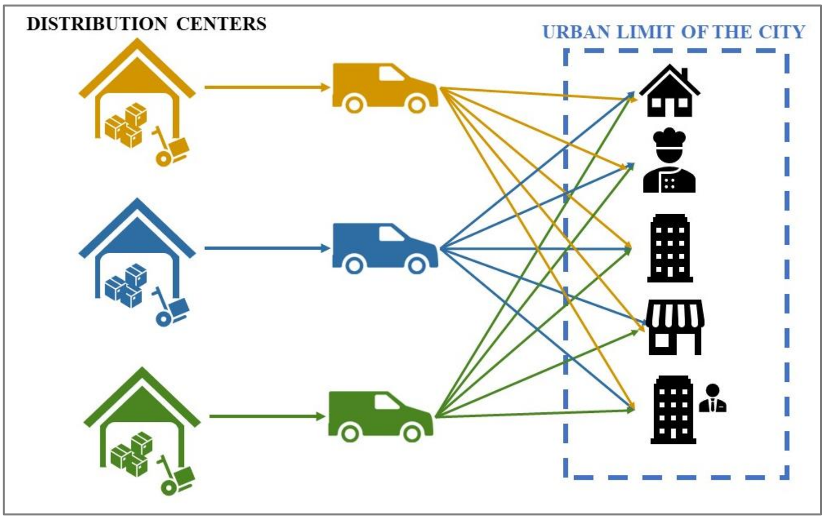

Figure 14: Representation of actual last mile distribution model in Kaunas.

On the other hand, this system is generating an inconvenience with the entrance of large dimension trucks in urban zones, the duplicity of travels planned by different companies, as well as an unnecessary sum of generated mobility that could have been avoided.

3.3.3. Regulatory authorities and framework

Kaunas has different authorities' levels that are in charge of planning and setting goals in mobility planning. Public administrations handle urban transports in order to set a convenient regulation, that is, fair rules that will help the maintenance of social order. Figure 15 helps understand this hierarchy.

- **European Commission**

Transport is a key element for European integration, and it is very important to guarantee the free flow of persons, goods, and services. Thus, transport is an essential sector for the functioning of the economy.

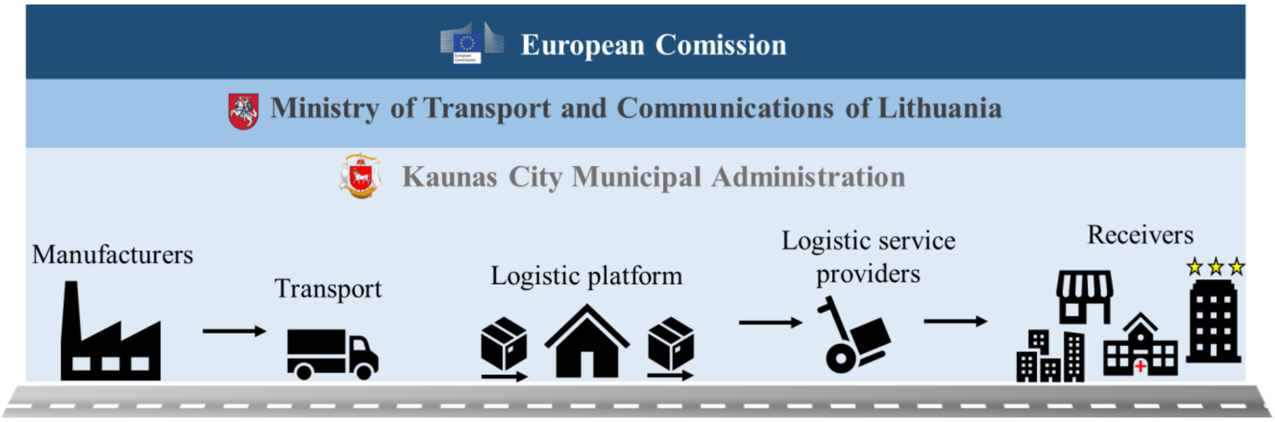

Figure 15: Kaunas Urban Freight Distribution scenario.
Source: Own elaboration.

In short, the European Commission works in collaboration with the countries to develop a modern transportation infrastructure network, set regulations as seen in Table 1, set the main goals to plan the future mobility and finance concrete initiatives with European projects like Civitas[7].

- **Ministry of Transport and Communication of Lithuania**

The Ministry of Transport and Communication of Lithuania represents the executive authority. Its mission is to develop secure transport and communication services that meet the needs of society. The ministry sets regulation, planning, and coordination in the following areas:

- Building and managing all mode transport infrastructure.
- Carrying the passengers' freight transportation by all modes (rail, road, inland waterways, and air).
- Road safety.
- Intermodality, logistics, and transit.
- Transport digitalization.

[7] CIVITAS is a network of cities for cities dedicated to cleaner, better transport in Europe and beyond. Since it was launched by the European Commission in 2002, the CIVITAS Initiative has tested and implemented over 800 measures and urban transport solutions as part of demonstration projects in more than 80 Living Lab cities Europe-wide.

- Special transportation of goods like dangerous goods in all modes.

- **Kaunas City Municipal Administration**

Kaunas Municipality is the one that handles the specific transport elements. It has jurisdiction in the main transport issues that directly affect the city. However, some infrastructures are out of its control although it is taken into account to coordinate plans. Kaunas' main efforts at the time of regulating transport issues are focused on sustainable mobility, but more concretely in public transport, and infrastructure areas. Apart from these preferences at the time of planning, Kaunas City municipality is in charge of regulating and developing the following areas:

- Public Transport
- Infrastructures (cycle lanes, traffic lights, pedestrian zones, etc)
- Non-motorized transport systems
- Taxi
- Parking areas and regulations
- Safety
- Sustainable mobility

3.4. Development plans and policies

Plan and policies, as well as the administration jurisdiction, are focused on handling the issues that are under each administration umbrella. As the administrative levels are lowered, the restrictions are increasingly restrictive. Regulation of the European Union cannot be contradicted by the Kaunas city council, instead, it can only add a more restrictive regulation along the same lines. In other words, EU regulations and decisions become binding automatically throughout the EU on the date they enter into force. Likewise, directives must be incorporated by EU countries into their national legislation. Each directive contains a deadline by which EU countries must incorporate its provisions into their national legislation and inform the Commission to that effect.

In respect to the development of the present project, the base and origin for its creation has been the development of measures driven by the municipality of Kaunas. These are going to be seen hereunder. Nevertheless, administration plans in EU countries work as a gear where the EU decisions trigger an effect on lower levels of administrations in their decisions making. In other words, it is going to be seen how the strategies set by the EU, have their direct impact on citizens through municipalities' plans. And thus, it is not only Kaunas municipality plans that affect Kaunas city, but all levels of administration.

3.4.1. European strategies

European strategy and plans towards the transportation sector have been moving around the low-emission mobility and the reduction of the environmental impact of transport activities. To ensure Europe stays competitive and will be able to respond to the increasing mobility needs of people and goods, the Commission strategy sets clear and fair guiding principles to the Member States to prepare for the future. From all the different plans that UE is launching towards the challenging and complicated future scenario, it is going to center the focus, for its interest, on the following ones:

- **A European Strategy for low-emission mobility**

The European strategy for low-emission mobility was set in 2016 and was under the program Horizon2020[8]. The main purpose of this strategy is to set some goals and guidelines to achieve and follow. As will be seen, the main part of the guidelines pursued by the strategy are still valid for the European Green Deal program. The guidelines are the following:

  - Digitalization of the transport sector, smart pricing, and a shift into a lower emission transport mode as tools to increase transport efficiency.
  - Speeding the deployment of low-emission alternative energy for transport
  - Moving towards zero-emission vehicles.

The strategy remarks on the cruciality of cities and local authorities at the time of delivering the strategy. The strategy aims to be a toolbox for local administrations to perform policies that can generate a substantial change to achieve the set goals.

The plan was supported with a fund of 39 billion EUR, in which 12 billion EUR where for low-carbon and sustainable urban mobility.

- **The European Green Deal**

European Green Deal is Europe's new growth strategy, a long-term plan that has as last step achieving UE emissions neutrality by 2050. The plan involves a lot of different themes and not only transport. Nevertheless, due to the high incidence of transport in greenhouse gas emissions, the plan has an important focus on transport activities. More concretely, transport focus is set on the digitalization of the sector, to achieve more efficiency, and sustainability, to face the climate change challenge.

The agreement foresees a 90% reduction in greenhouse emissions by 2050. From this 90% of emissions, 71,7% corresponds to the transport emissions quote. To achieve this objective, the agreement pursues the following strategies:

  - Increase the efficiency of transports with intermodality.
  - Set transport prices that reflex the environmental impact.
  - Boost the supply of sustainable alternative fuels for transport.
  - Reduce pollution.

3.4.2. Lithuania's National program for transport development 2014-2022

Lithuania's transport planning is a medium-term strategic planning document, which sets out the strategic goals for transport development. The planning of the transport strategies in Lithuania is in charge of the Ministry of Transport and Communications.

As a European Union member and as an important hub of European transport the plan counts with the support of the structural funds of the EU. The program has been prepared based on EU and national legal acts, strategies, and branch (sectoral) strategies: The State Progress Strategy "Lithuania's Progress Strategy, Lithuania 2030".

[8] Horizon 2020 is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness.

The main strategic objective of the program is to create a Lithuanian sustainable transport system, respectful with the environment, competitive and of high added value.

The plan is focused on global challenges such as climatic change, energetic efficiency growth, mobility demand management, and the development of new sustainable mobility habits. Further on it is explained the five main lines of action pursued by the strategy:

- Improve the trans-European transport network. In Lithuania, improve the North Sea-Baltic Corridor (TEN-T).
- Increase the competitiveness of the transport sector and improve the quality of transport and logistics services through an active transport policy.
- Improve infrastructures to reach better connectivity in key places like Klaipeda port or the North Sea-Baltic corridor either by road or train.
- Increase energy efficiency in transport and reduce the negative environmental impact of transport.
- Increased safety and security improved traffic management through ITS and other new features.

3.4.3. Kaunas development plans

- **Kaunas Strategic Development Plan 2022**

After being selected as the European Capital of Culture[9] for 2022, the city of Kaunas is facing a modernization process to face its projection to Europe and the world. This represents an important opportunity for the city to generate considerable cultural, social, and economic benefits and it can help foster urban regeneration, change the city's image, and raise its visibility and profile on an international scale.

With this purpose, it has been launched the Strategic Development Plan that aims to turn Kaunas into a sustainable and civic-minded city, leading in advanced business and innovation, a center of modern and involving culture, home to learning, and happy people. In terms of mobility and transport, Kaunas development Plan focuses its attention on the modernization of pathways, cycleways, generating a safe environment for pedestrians or drivers, and finally create the necessary infrastructures to ensure an attractive city environment.

- **Kaunas Sustainable Mobility Plan 2030**

Kaunas Sustainable Mobility Plan is a long-term plan that pursues to change the mobility landscape of Kaunas. The plan has its starting point on the report's analysis of how to promote sustainable mobility in nine key areas for the city:

  - Public transport promotion
  - Non-motorized transport integration
  - Modal trips
  - Traffic safety security

[9] A **European Capital of Culture** is a city designated by the European Union (EU) for a period of one calendar year during which it organises a series of cultural events with a strong pan-European dimension.

- Traffic organization and improvement of mobility management
- City logistics
- Inclusive city design
- Alternative fuels and environmentally friendly transport promotion
- ITS development

The key area that is in common interest is the City Logistics, concretely the measures that the plan proposes in order to reduce the impact of inner-city logistics. These are the measures that have inspired the realization of the present project, as it may be seen, below are presented the original plan proposals:

- Consolidation and delivery service in certain areas.
- Set distribution service intervals.
- Promote cleaner (electric) and little vehicles.
- Assess the possibility of the development of logistics centers in the city.

The plan also considers 4 more measures regarding the logistic impact of Kaunas outbounds:

- Form a network of streets and roads of A1, A2 categories of uninterrupted traffic, which will consist of the main road Vilnius – Kaunas – Klaipėda, the main road Kaunas – Marijampolė – Suwałki and until 2022.
- Integrate the city street network into the uninterrupted traffic bypass system by installing new street routes and different levels of connections.
- Build a south-eastern bypass, to form a network of category B streets, to allocate the central part of the city to environmentally friendly modes of transport.
- Further develop Kaunas FEZ, industrial districts, to promote the development of new industrial facilities in these territories.

Especially, the present project wants to focus on the first measures that are more related to inner-city logistics. As will be seen below, during the measure's development, some of the measures have been modified to give more criteria to the whole proposal. Moreover, with the reformulation of the measures this project aims to provide a better approach to obtain suitable solutions for the city.

Finally, it is also remarkable from the Kaunas Sustainable Mobility Plan, the creation of a *CO_2 Free Zone* in Kaunas city center. The measure aims to establish tolls at the entrance of the city center to avoid traffic. The measure would not affect zero-emission vehicles and it is expected to be implemented in 2030. It exists nowadays a prevision of where this entrance restriction would be applied (see *Figure 16*).

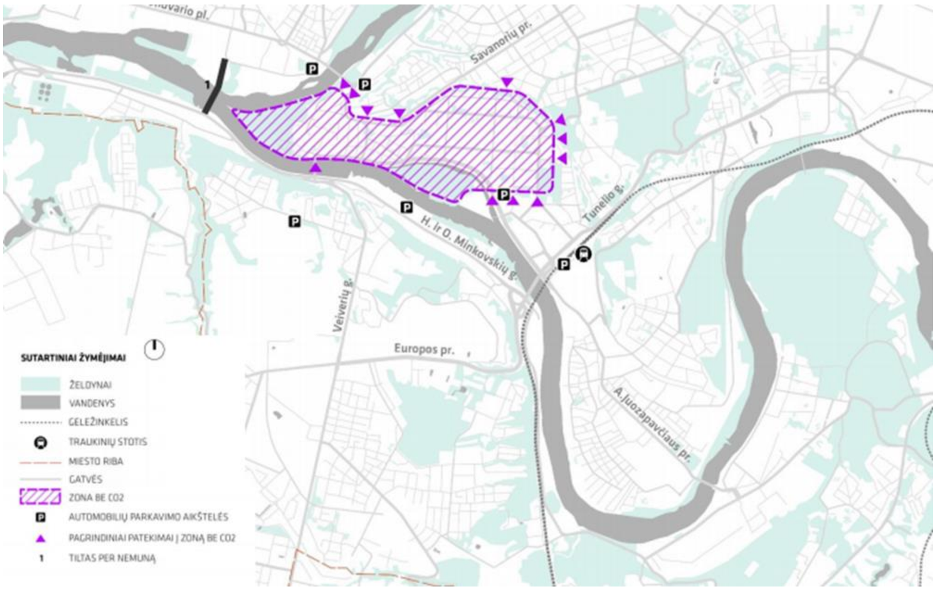

Figure 16: Kaunas 2030, CO_2 Free Zone.
Source: Kaunas Sustainable Mobility Plan 2030.

3.5. Trends in Urban Freight Distribution

Last-mile distribution of goods, urban freight transport, and household deliveries are activities that affect the normal development of city mobility. Also, as it has been explained, there are other serious consequences to the environment or citizens' welfare. All large urban areas in the world are facing this situation.

Administrations and municipalities around the world have been setting different measures, trying to obtain the best results in reducing the impact of these activities and also trying to obtain more efficient and competitive logistics systems. They apply measures around the factors that affect freight transport:

- Regulation and territorial planning
- Infrastructures
- Vehicles

The following map (see *Figure 17*) is a resume of the different measures and its type in different European countries. There is a clear tendency for each country to develop a specific type of measure. For example, in Norway, the tendency is to apply urban road tolls, in Germany there exists a priority for the creation of low emission zones or in Italy for applying other access regulations. Different countries are taking measures in their main urban areas. However, Lithuania has not implemented any measure in any of its 3 main cities; Vilnius, Kaunas, and Klaipeda.

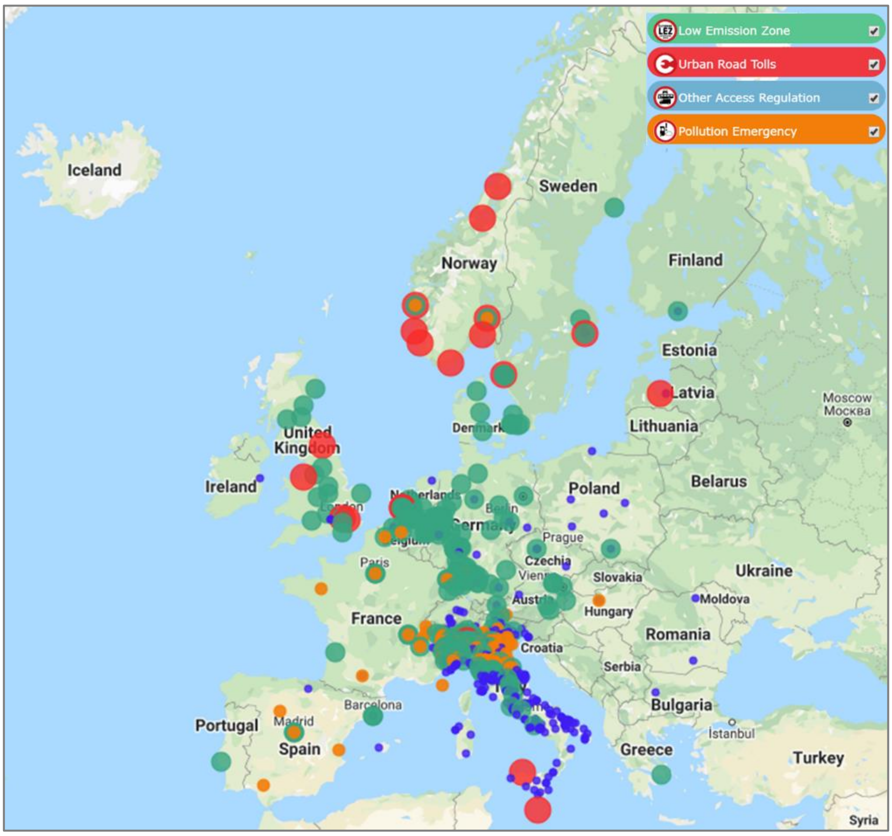

Figure 17: Urban Acces Regulation in Europe.
Source: Urbanaccesregulations.eu

This section will do a benchmarking of the measures that have been taken in other cities around these factors. With this, the objective is to understand what are the measures that are succeeding in other cities, how are these implementations driven, why is the measure successful, etc.

In this way, knowing what the critical parts of each implementation are, it will be easier to understand the key elements for the success of this project. Besides, understanding each implementation will allow gaining some background to avoid future errors.

3.5.1. Low Emission Zones

Low Emission Zones (LEZ) consist on establishing a delimited area of a city in which the air pollutant levels are worrying and set access restrictions or prohibitions to those vehicles that pollute more. In Europe, the criteria to set these regulations is engine emission regulation (see Table 2).

The objective of the measures is the modernization of cities' vehicles fleet. As it has been explained previously, the older the vehicles, the more they pollute. Therefore, this type of measure is commonly followed by public aids for citizens purchasing cars.

- **LEZ in Barcelona**

A recent example of implementing this measure is the city of Barcelona. Through an environmental hallmark system, the city council classified all the vehicles of the city. Petrol cars (M1) that are older than regulation Euro 3 (before 2000) or diesel cars (M1) that are older than Euro 4 (before 2005/2006) were not receiving any environmental hallmark and thus, by 2020 they are not allowed to circulate anymore inside the LEZ. For motorcycles (L) that are older than regulation Euro 2 (before 2003) has happened the same.

Progressively, the city council is going to apply in 2021 similar measures for light freight vehicles (N1), trucks (N2, N3), and buses (M2, M3) without environmental hallmark. These vehicles are going to be under the same Euro restrictions as diesel and petrol cars (N1).

With this measure, the city council of Barcelona was pursuing a reduction in the number of vehicles circulating in the city and renovate the older ones. Measure application has been driven by different stages:

- The LEZ started in 2019 but was only applying during the days in which the city was registering pollutant episodes. Citizens were informed of these episodes via the city council website. Moreover, it was an email alarm system available for those citizens who requested.
- In 2020 starts the second stage with the official beginning of the LEZ. The LEZ only applies during working days from 7 am to 8 pm.
- In 2021 the measure will apply also for freight vehicles. For the rest of the drivers, by the moment there are no further measures announced.

Barcelona’s implementation represented a sudden change for citizens. In a matter of 2 years, many citizens were forced to change their vehicles. Due to complaints from some sectors and specific unions, the city council was forced to grant some exceptions. These exceptions are treated individually to ensure the correct use of the regulations. However, vehicles with especial use, passengers with reduced mobility, or vehicles in essential or emergency services are exempted from the LEZ.

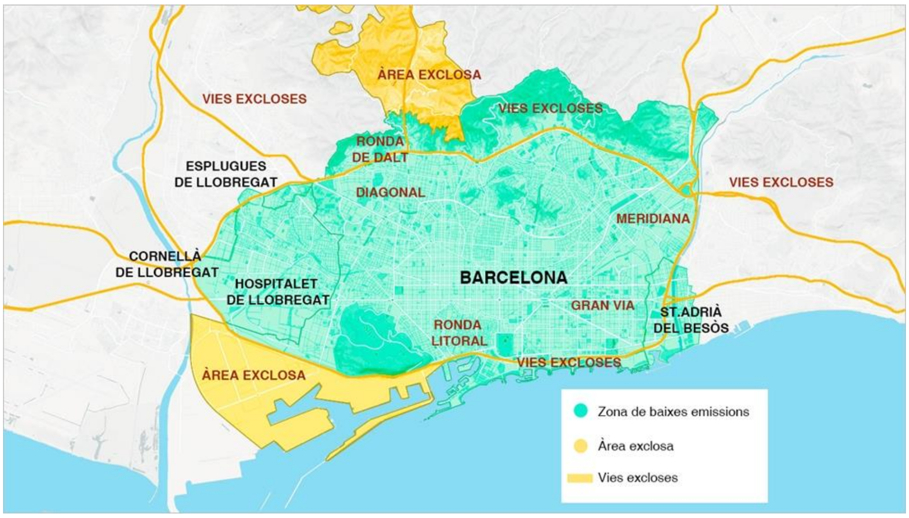

Figure 18: Barcelona's Low Emissions Zones (in blue).
Source: Barcelona city council

Finally, to ensure and facilitate citizens' adaptation to the measure, the city council launched a package of municipal aids. Among other aids, the city council offered 3 years of free public transport for those drivers who scrap their car, aids for an electric car acquisition, and a change in the public transport tariffs to benefit common users.

- **LEZ in Brussels**

Brussels city council has adopted similar measures to Barcelona. It also has created LEZ to improve the air quality of the city. As in the case of Barcelona, the implementation has different stages of implementation. Every year more restrictive measures are taking effect. The measures are set from the year 2019 to the year 2025. Restrictions are also affecting vehicles from categories M1, L, N1, M2, and M3. To identify the vehicles, the city council has created an official register where all local drivers should register to circulate. Besides, the LEZ is having a permanent character 24 hours/day the 7 days of the week.

Diesel vehicles are the ones who will suffer more restrictive measures. Nowadays, restrictions are set for vehicles under Euro 4, however, for the year 2022 the restrictions are going to be for vehicles under Euro 5, and in 2025 restrictions will be applying for vehicles under Euro 6.

Petrol vehicles, by contrast, nowadays are only having restrictions for vehicles under Euro 2 and it will not be till 2025 that the restrictions will change to vehicles under Euro 3.

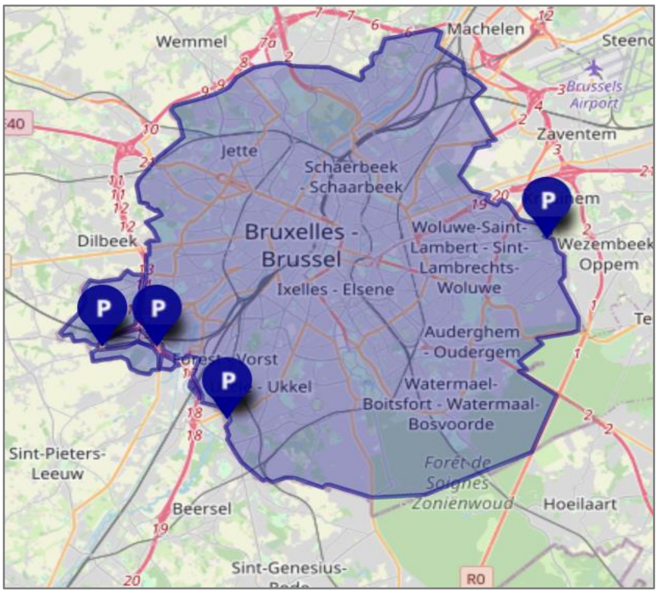

Figure 19: LEZ Brussels.
Source: Brussels city council

3.5.2. Urban Road Tolls

Urban road tolls are measures that pursue reducing congestion and thus, pollution in certain “reduced” areas. This action has been considered by experts of many countries as the most effective solution to its purpose. Nevertheless, the measure is applied to reduce congestion originated by particulars in favor of better public transport service and in some cases, to improve freight distribution flows.

- **Ultra-Low Emission Zone in London**

London city council has launched what they have called the Ultra-Low Emission Zone. It is an area inside the LEZ of London in which there is a more restrictive LEZ. The so called ULEZ is a delimited zone where the access is restricted by tolls for those vehicles who do not meet the restriction parameter.

To help improve air quality, ULEZ operates 24 hours a day, 7 days a week, every day of the year, except Christmas Day, within the same area of central London as the Congestion Charge. Most vehicles, including cars and vans, need to meet the ULEZ emissions standards or their drivers must pay a daily charge to drive within the zone:

- £12.50 for most vehicle types, including cars, motorcycles, and vans (up to and including 3.5 tonnes).

- £100 for heavier vehicles, including lorries (over 3.5 tonnes) and buses/coaches (over 5 tonnes).

The ULEZ standards are:

- Euro 3 for motorcycles, mopeds, motorised tricycles and quadricycles (L category).
- Euro 4 (NOx) for petrol cars, vans, minibuses and other specialist vehicles.
- Euro 6 (NOx and PM) for diesel cars, vans and minibuses and other specialist vehicles.
- Euro VI (NOx and PM) for lorries, buses and coaches and other specialist heavy vehicles (NOx and PM).

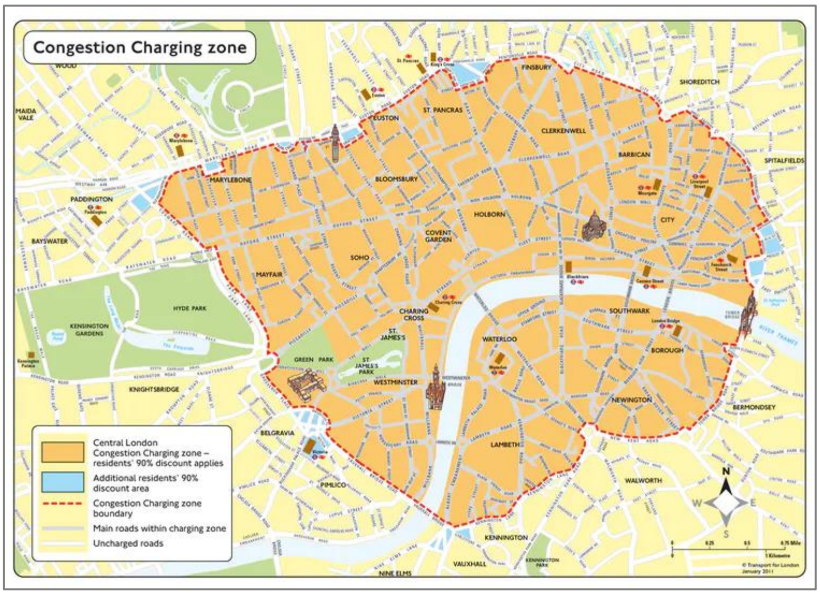

Figure 20: Londo Ultra-Low Emission Zone.
Source: Transport for London

After applying the measure, Transport for London reported that the charge reduced traffic by 15% and congestion – that is, the extra time a trip would take because of traffic- by 30% (Badstuber, 2018). The measure has reduced traffic volumes in a quarter lower than a decade ago, allowing central London road space to be given over cyclists and pedestrians.

An important move to achieve these numbers was the introduction to the bus network of 300 new extra buses. With this, 29.000 more passengers had entered the charging zone by bus during 2014. It stresses that no restrictions can be done without offering alternatives to citizens.

- **Stockholm Regulated Access**

Stockholm also has applied a tax to access the city center of the city. The congestion tax was implemented permanently in 2007 after a seven-month trial period between in 2006. The primary purpose of the congestion tax is to reduce traffic congestion and improve the environmental situation in central Stockholm. The funds collected are being used for new road infrastructures in and around Stockholm.

The system works in a similar way to London, there are cameras in the entrances of the restricted area that takes pictures of all cars plate that enter the zone. The picture is sent to the Swedish Transport

Agency where the vehicle is identified. Then the Swedish Transport Agency sends a payment slip to the owner of the vehicle if the vehicle is registered in Sweden. If the vehicle is not registered in Sweden, there is also a procedure to obtain payments from the owner of the vehicle.

The existing difference between London's system remains in the way prices are fixed. In Stockholm, prices vary from 11 and 45 SEK, depending on the season and traffic demand. With this, the tax adapts to the demand at every time and always achieves a similar level of congestion regardless of seasoning. On the other hand, the price system also takes into account the number of hours that the vehicle remains inside the area.

3.5.3. Lorry Circulation Restrictions

These measures consist of restricting access to a specific vehicle typology to certain zones or roads of a city. The objective of these restrictions is to reduce traffic congestion and environmental impact.

Generally, these measures are applied to prevent access to the city to large-scale vehicles. Sometimes the restriction is done just during sometimes of the day others are permanent.

- **Dublin's Cordon Restrictions**

The measure was though when the Dublin Port Tunnel opened on 20 December 2006 providing direct access between Dublin Port and the national road network for Heavy Goods Vehicles (HGVs). Dublin City Council introduced the HGV Management Strategy to encourage maximum use of the Port Tunnel by port-related traffic and to enhance the city center environment.

The HGV Strategy provides for a ban on 5+ axle vehicles during the hours of 07.00-19.00 seven days a week from a designated cordon area and provides a limited permit scheme for 5+ axle vehicles that need to load/unload within the city center area.

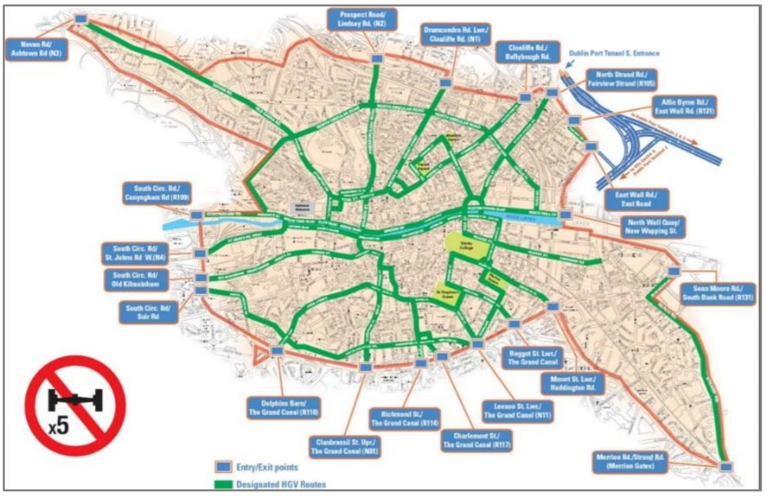

Figure 21: Heavy goods vehicles. Cordon Restrictions Dublin. Source: Dublin City Council

The measure application has reduced between 80% and 94% of the number of trucks entering the city center. With this reduction the quality of the air has improved, an air quality measurement station located in the city center registered on average 36% less concentration of PM_{10}. The concentrations decreased from 35,5 $\mu g/m^3$ before the implementation to 22,7$\mu g/m^3$ after it (Dublin City Council, 2020).

3.5.4. Multiuse lanes

Multiuse lanes are a measure that aims to adapt the use of some lanes to different needs during the day. During the hours of high traffic, the lane is used for vehicle circulation or public transport, during the hours of medium traffic the use is for load and unload, and during the night where demand is low, its use is for vehicles parking.

- **Bilbao's Multilane**

In Bilbao's multilane use, there is a well-defined schedule to regulate the lanes use:

  - From 8 am to 1 pm the lane is used to load and unload operations.
  - From 1 pm to 8 pm the lane is used for vehicle circulation.
  - From 8 pm to 8 am the lane is used for vehicle parking.

This measure does not reduce the traffic in the city; however, it reduces the congestion creating more fluid flows. It is important to set clear vertical signals that avoid any confusion to users.

Figure 22: Multilane signaling.
Source: Bilbao City Council.

The experience has proved that this measure is not able for every street. The measure could be a good option for those streets that have an important mobility with many different purposes and in very congested and densified city spaces. Moreover, it is necessary a minimum number of 2 lanes in the same direction to implement the measure and special city characteristics to be able to block one lane without affecting the circulation in excess.

3.5.5. Innovative Logistics Models

- **Vanapedal (Barcelona)**

Vanapedal is a last-mile delivery company that started in 2010. The company performs last-mile logistics services using electric cargo bikes. The initiative contributes to pacify pedestrian areas by using non-polluting vehicles. It is a private initiative that counts with Barcelona City Council support.

Vanapedal offers an ecologic, efficient, and rational service to support transport operators and e-commerce companies in delivering their goods in difficult access areas with time restrictions into the city center and historic center. This activity is also complemented with an advertisement service on the walls of the cargo bikes box. Thus, Vanapedal wants to be located as the last step in urban distribution for service logistics providers and companies.

Barcelona city council selected Vanapedal to drive the first pilot test in the district of Ciutat Vella. The pilot test was based on a micro logistic platform that works with two mini-docks, one for loading and the other for unloading, and from where, by means of electric tricycles, the distribution of goods is carried out through the streets of Ciutat Vella.

Figure 23: Vanapedal distribution network in Ciutat Vella (Barcelona).
Source: Vanapedal

The tricycles can carry 180 kg of freight in an efficient and fast way. The electric tricycle model weights 105 kg and has a closed rear cabin of 1,5 m^3 of capacity. The power of the vehicle is limited by law to 250 watts. Its use is regulated by the European Directive 2002/24/EC of March 18. The battery has an autonomy of 5 hours and every tricycle saves 2 tons/year of CO_2.

Figure 24: Cargo bike.
Source: Vanapedal

The pilot test was aiming to achieve 120 operations per day with 16,8 km traveled per vehicle/day. With these it was expected 5,3% reduction light and heavy freight distribution vehicles, and thus 225 km less in pollutant travels (Barcelona Centre Logístic Catalunya, 2016).

After the two years of pilot test, the company was having 7 operative routes in which was distributing 58,4 packages/bike/day. In one of their informs, the company was pointed that in 3 months and operating with 4 bikes the save was around 550 liters of fuel, 1.452 kg of CO_2 and 1.100 kg/km de NO_X (M. Ferri, 2012).

Nowadays, the company has exported the logistic model to different districts of the city like Rabal, Gótico, Barceloneta and Gracia. It has started to collaborate with important logistics service providers like SEUR in Ciutat Vella. The breaking bulk is done in the street in the available spaces that have obtained with the help of the City Council to avoid the high real estate costs of the city. One of its lasts challenges has been the management of an important supermarket’s delivery service. However, the experience failed due to time and effort in multi-story buildings without an elevator.

- **Sogaris (Paris)**

Due to the increase in the complexity of the logistics in the large urban area of Paris, the logistic service provider Sogaris, has developed an innovative Logistic model to respond better to their client’s needs.
The company has built a logistics network to serve efficiently to their Paris clients. The model is based on three different layers that represent the different steps of the outbound logistics. These steps aim to reduce the number of travels, the serving time, and thus, their environmental impact and service quality.

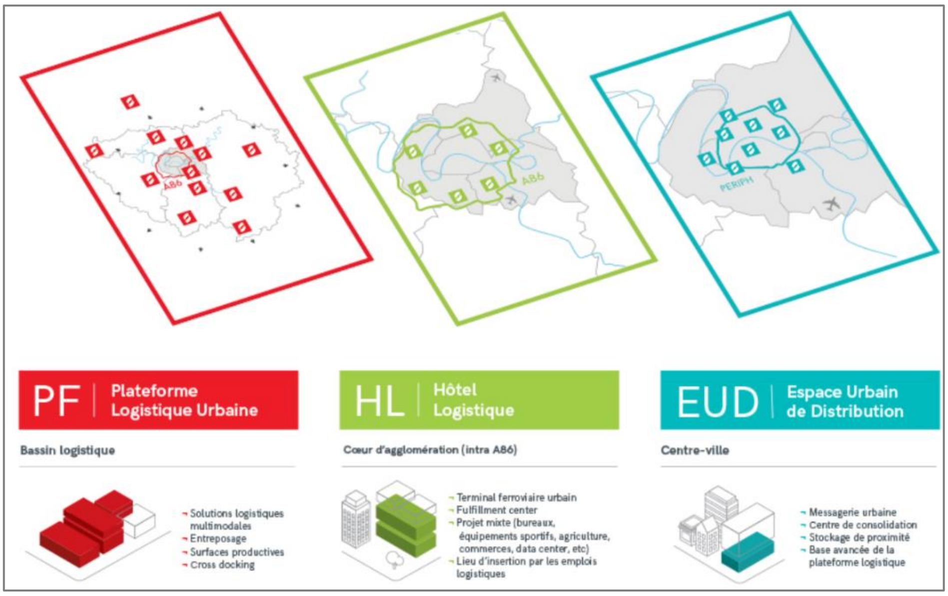

Figure 25: Sogaris logistic structure.
Source: sogaris.fr

Logistic platforms are the first layer of this logistics system. These platforms can be found in the outbounds of Paris but near to the main flows of goods. They represent the consolidations points from where goods arrive in different transport modes. In short, they act as the connection between long distance freight flows and urban freight distribution. Precisely, intermodality is a very important element for the success of this platforms. Sogaris has strategically establish these platforms near the main Paris intermodal logistic infrastructures.

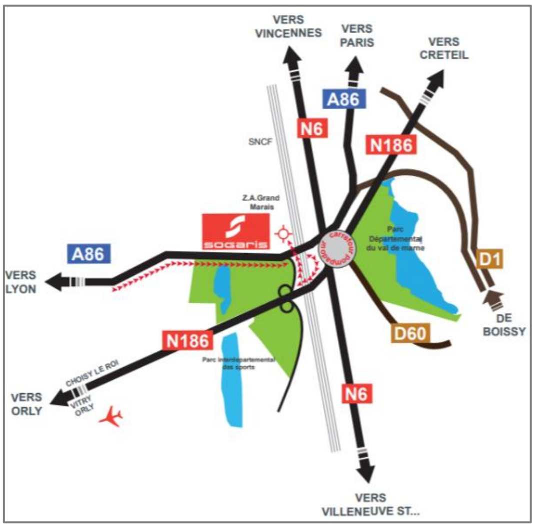

Figure 26: Sogaris Creteil Logistic platform.
Source: Sogaris.fr

Shows the location of the Sogaris logistic platform in Creteil. The platform has a strategic location due to its proximity to Paris (6 km), its connections with Orly airport, and the Intermodal rail-road logistic platform. Besides, it is near the main road flows in the south of Paris. Creteil is a platform based on 3 warehouses with 36.709 m^2.

On the second level, there are urban consolidation centers[10]. These spaces are located in the outbounds of the low emissions zones or the entrance doors of the city. The paper of these infrastructures is to integrate the logistic activity of the city.

Finally, in the third layer of the logistic system, there are urban distribution centers. These infrastructures are located inside the city and promote freight distribution through less polluting vehicles.

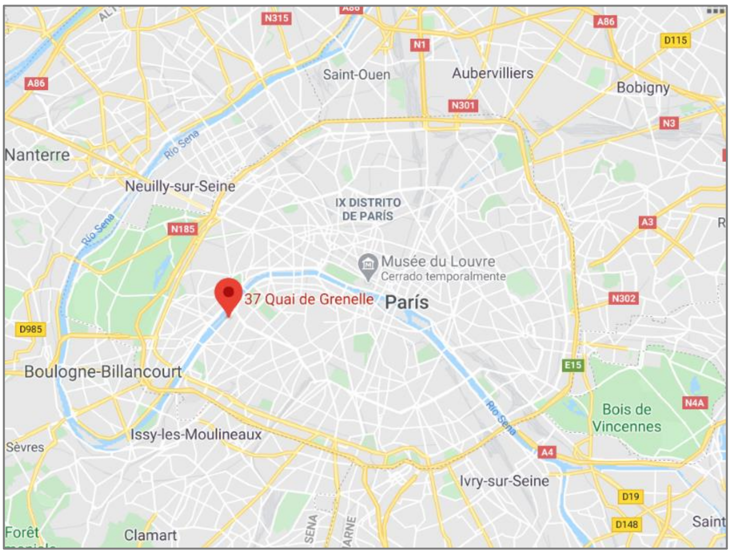

Figure 27: Sogaris Urban Distribution Center in Paris.
Source: Sogaris.fr

[10] Urban Consolidation Centers (UCC) are operational concepts that reduce freight traffic circulating within a target area by fostering consolidation of cargo at a terminal. In most cases, carriers that otherwise would make separate trips to the target area with relatively low load factors, instead transfer their loads to a neutral carrier that consolidates the cargo and conducts the last leg of the deliveries. Conceptually, this may include “joint delivery systems”, “cooperative logistics,” and “urban distribution centers,” although strictly speaking, these operations are not necessarily equivalent to a UCC.

From these points the capillary distribution of the merchandise to the different nearby neighborhoods is carried out. An important element for the economic viability of the project is that these centers are used in a shared way with other logistics providers so that they are always working at high levels of capacity.

- **Kaunas pickup points**

Pickup points are convenience points, where online purchased goods are delivered by postal services and are collected by particular customers. There are two types of convenience points: automated mailboxes and proximity retailers.

The use of pickup points has become popular. This increase is due to the significant growth of e-commerce. These infrastructures reduce the number of failed deliveries and the number of transports. These infrastructures sometimes represent a good choice for those customers who are looking for close, easy accessibility and long opening hours systems. Besides, pickup points do not impede devolution operations.

Nowadays, pickup points are found in many cities. Most logistics service providers or postal services have created own networks. Kaunas also counts with its pickup points network. Nevertheless, the pickup points network is driven by private initiatives and they are independent networks inside the city. In Kaunas there are 3 main networks with 35 pickup points (LP Express), 14 pickup points (DPD), and 3 (Venipak). As may be seen in Figure 28, the network is spread in almost all Kaunas neighborhoods, having more presence in areas with more population and economic activity.

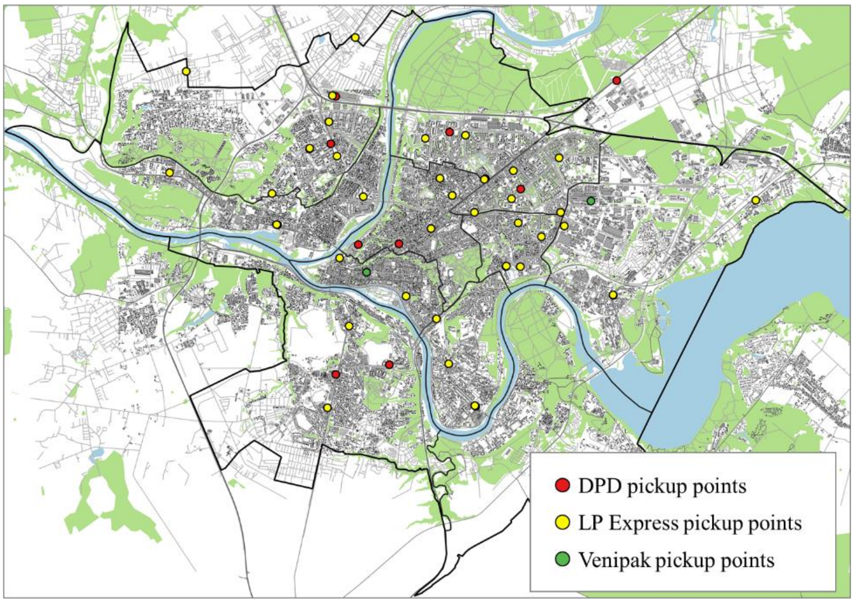

Figure 28: Pickup points networks in Kaunas.
Source: Own elaboration according to Venipak, LPE and DPD data.

Figure 29 shows the coverage area of the different pickup points. The coverage area considers an approximate maximum distance of 5 minutes from the pickup point to the further location of coverage, what it is traduced in 400 metros. There is not an absolute coverage, but most of the pickup points are generally located in frequented spaces like supermarkets, malls, gas stations, etc. The use of these pickup points does not represent a unique solution but it may be a good option to cover a significant part of the demand.

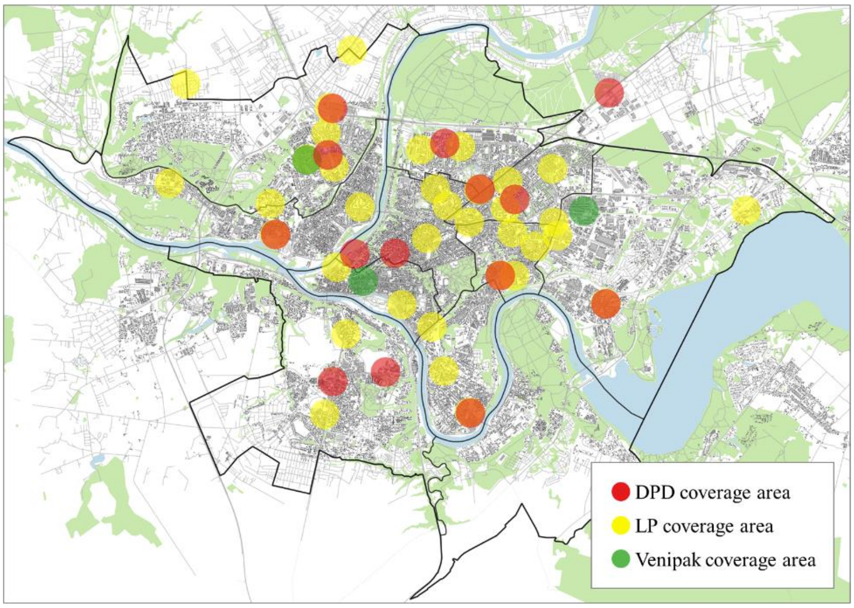

Figure 29: Coverage area of pickup points.
Source: Own elaboration according to Venipak, LPE and DPD data.

4. Measure definition

This chapter is focused on developing a conjunct of measures that pursue to generate a new more sustainable urban freight distribution scenario in the city of Kaunas. As has been said previously, the proposal is born in the original measures of the *Kaunas Sustainable Mobility Plan 2030*, exposed in section *3.4.3.*

The present project is focusing just on those measures that are related to urban logistics, the ones that happen inside the city. Nevertheless, all measures are considered to avoid carrying out proposals that are in dissonance with the set ones by the original plan or with future development plans. The measures that are going to be developed in this project are the following ones:

- Asses the possibility to develop urban logistics centers in the city of Kaunas.
- Implementation of a last-mile distribution system by electric bicycles.

4.1. Asses the possibility to develop urban logistics centers in the city of Kaunas.

Logistics Center is a center in a defined area within which all activities relating to transport logistics and the distribution of goods, are carried out by various operators on a commercial basis. The purpose of establishing distribution centers inside the city of Kaunas is to increase efficiency in goods distribution. An urban distribution center works as a hub where the goods are consolidated and after, transported to the different final destinations through zero-emission vehicles.

If it is kept the previous scheme of *Figure 14* (p.36) as a reference, this system increases last-mile distribution efficiency:

- With urban logistics centers goods are sent from distribution centers to the urban logistic center without having to think on different routes. Due to this structure, it is possible to send bigger trucks to the urban hub, grouping in one vehicle more than one route.
- When shipping goods from the urban hub to the final destination, it is possible to organize more efficient routes pooling goods from the different individual distributors. Thus, urban logistics centers open the possibility to create a collaborative framework between supply chains from different companies and logistics service providers.

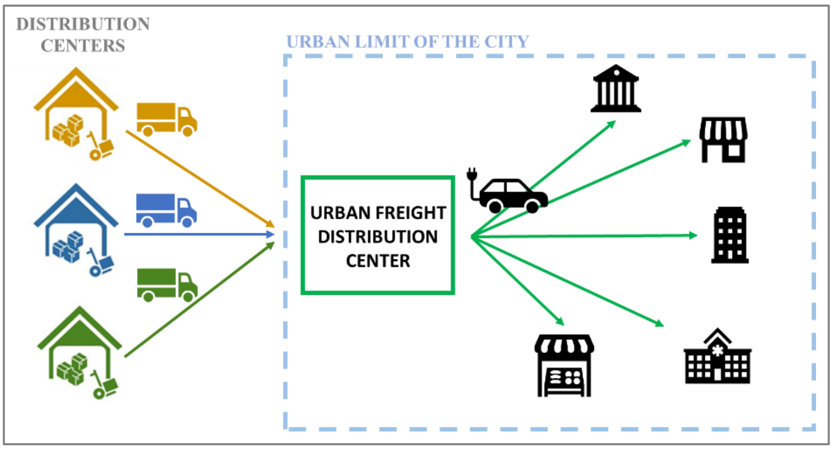

Figure 30: Last-mile distribution system structure with urban freight distribution centers

Urban freight distribution centers change the structure of the last-mile distribution system. See *Figure 30* to understand how this measure changes from the actual scheme in *Figure 14*.

4.1.1. Objective

Considering the realized sector characterization and the possible needs that logistics centers would satisfy; the objective is to establish a logistics center in the city. This logistic service will cover the most interesting areas in terms of demand.

To generate a significant change in the environmental impact, the measure also pursues a change in the last-mile distribution. In this way, the purpose is also to perform the last-mile distribution by zero-emissions vehicles.

4.1.2. Operation

The objective of this distribution center is to work as a cross dock. The main characteristic of these infrastructures is that their stock is zero or almost zero. That means that this distribution center function is to prepare the orders to be sent as soon as possible. It will not work as a warehouse.

Therefore, the infrastructure needs a receiving area to process the arrival of packages and carry out the bulk break. From there, the packages should pass to the next stage where the orders are going to be prepared considering the different routes needed. Finally, the last stage is the shipping zone where the orders are loaded to the vans to be sent to customers. As it has been said, the deliveries are going to be done by zero-emission vehicles.

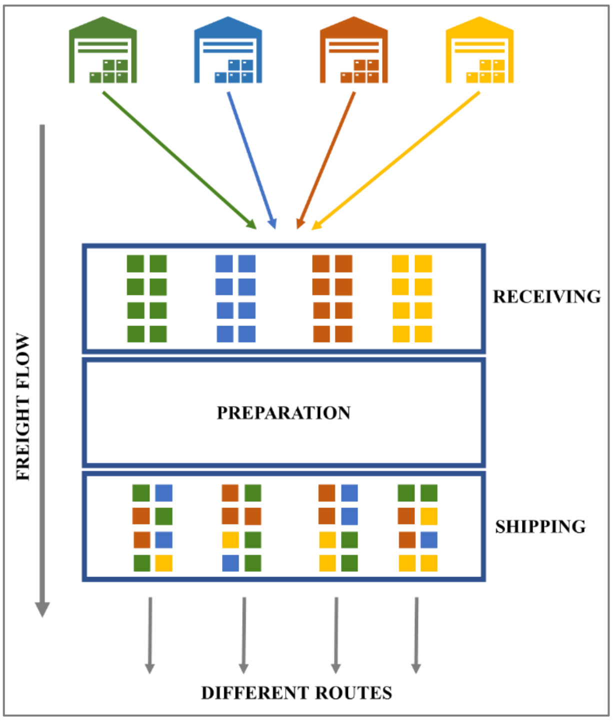

Figure 31: Urban distribution center structure

In *Figure 31* the logistic center has a linear flow where freight enters from one side and lives from the opposite side. This represents the most suitable situation, but sometimes the space requirements do not allow to organize flow in this way. For this reason, it can also be though on “U” distribution if the space only has one external face.

Another interesting issue in the operating field is the devolutions. It can be interesting to do especial routes just for devolutions. Some logistic providers keep the half of the truck empty for the devolutions, instead, the proposal is to do different routes for shipments and devolutions. In this way, vehicles will be fully loaded during shipments and will be also able to group more devolutions in one van by setting special routes for its purpose.

4.1.3. Beneficiaries

As it has been seen, there are many stakeholders related to urban distribution. Firstly, it is obvious that the number of beneficiaries is limited by the location and influence of the logistic center. Secondly, the logistics center aims to give service to as many activities and sectors as possible. However, not all activities and types of freight indeed fit in the operation of the logistic centers. Thus, it is thought that the logistics centers will suit perfectly to those activities that are used to operating with frequent shipments of packages with small or medium volumes. This can be the case of the Hotel and Catering industry, PEC (Parcel, Express, and Courier) or retailers. For this first implementation, it is thought as a key crucial element to gain the trust of businesses. They represent the economic motor of the city and having their approval would represent a solid guarantee for future implementations.

Finally, the logistics centers aim to be a key partner for the logistics service providers. It is with this sector, collaborating in the last mile of the delivery that the logistic center represents strong value. It can help these companies to reduce their costs and improve their time serving.

4.1.4. Selection of influence area

In previous chapter 3, it has been shown where different logistic actors are located in the city of Kaunas. After doing this analytic part, some city areas have shown a higher potential to be poles of goods movement. These areas are in the Centras, Gričiupio, Dainavos, Eigulių and Žaliakalnio neighborhoods (see *Figure 32*). The present project will focus on these areas to implement the urban logistics center. However, as it may be seen in *Figure 32*, the covered surface by this neighborhood is too extensive for a single distribution center. For this reason, it is required to establish some priorities that could end with the selection of the suitable influence area.

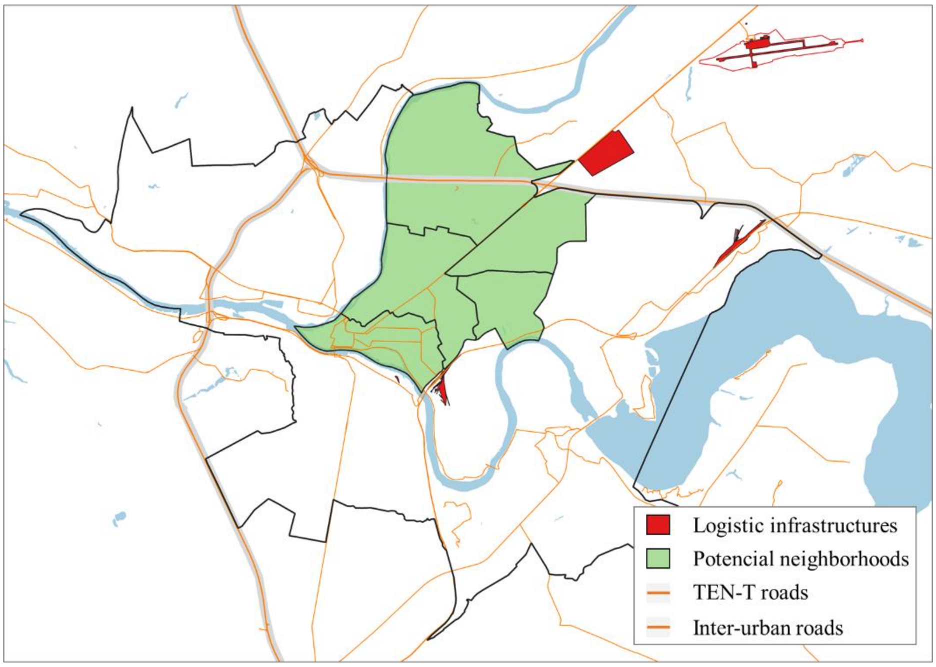

Figure 32: Selected neighborhoods for implementing urban logistics centers.

The selection of these criteria has been applied considering the characterization and study of cases previously done. In the following points has been explained the different criteria that have been taken into account at the time of selecting the influence area:

- Establish areas with an approximate maximum of 7 km^2, which has been studied to be the adequate surface so that, under normal traffic conditions, the estimated time between extreme points is approximately 12 minutes maximum.
- The existence of fast routes that allow the rapid flow of vehicles.
- Ensure the influence on main economic activity areas.
- The selected areas should be under conditions of easy access for road vehicles.
- Avoid barrier infrastructures: motorways, large green areas, etc.
- The influenced area must contain the 2030 planned CO_2 Free zone. The existence of an influence area is the perfect scenario for the implementation of urban distribution center that will benefit the different stakeholders by adding more options to its logistics chains.

By using these criteria, it has been delimited an influence area that is the sum of two areas; the CO_2 Free Zone and part of Savanorių pr. street and its surroundings. The sum of these two areas is considered a suitable surface to develop the urban distribution center. On one hand, the CO_2 Free Zone, located in the city center, represents an area where lots of retailers are concentrated. On the other hand, the Savanorių pr. is a street where many establishments can be found along its route. Savanorių pr. represents an important economic activity zone that stimulates the movement of goods within the city of Kaunas. In total, both areas cover a total approximate surface of 6,5 km^2.

As is will be seen in further sections, the existence of two differentiated areas inside the influence zone, is going to generate two types of transport. However, this will be explained in future sections.

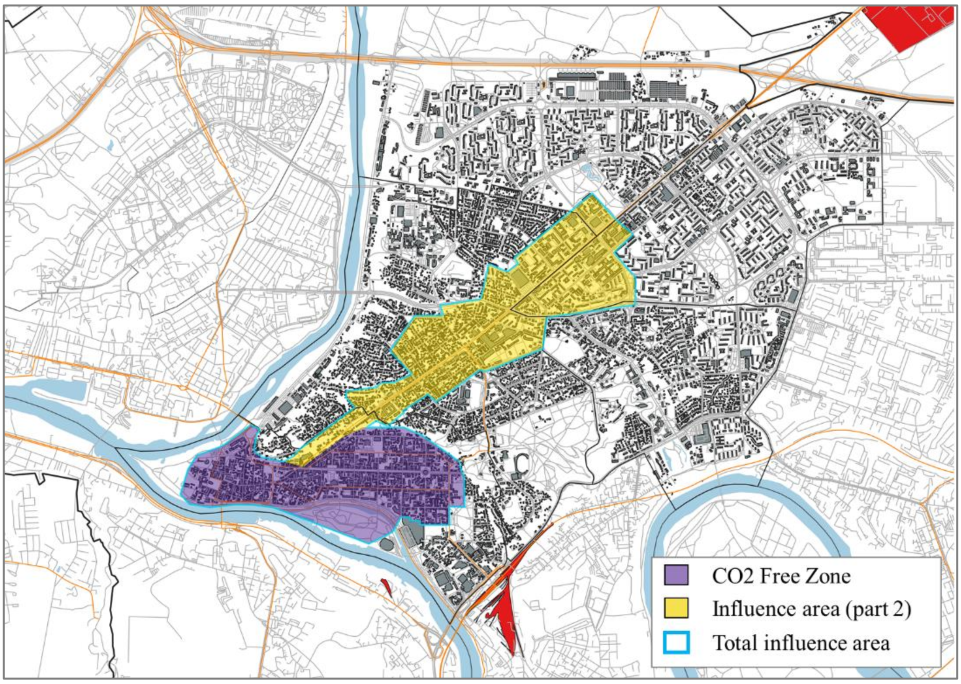

Figure 33: Influence area of the urban distribution center.

4.1.5. Selection of a location

Once it is defined the area that is going to be served, the next step is to set the concrete location of the urban distribution center. In other words, choose the location from where the goods are going to be sent to the different final destinations. In the location process there will be developed a conjunct of steps that would lead to a solution. This solution will try to satisfy as much as possible the set succeeding factors.

Step 0: Critical factors

The initial step in order to solve a location problem, is to fix the critical factors[11] that are going to rule the election of our candidate locations. In this way, two main aspects represent crucial for the urban distribution center development:

- On one hand, the urban distribution center needs to be in one of the main urban roads. The distribution center requires a good accessibility for guarantying the access to large freight vehicles. Besides, the direct connection with a fast-moving road will reduce the distances to the final destinations.
- On the other hand, because of special future conditions that will have the CO_2 Free Zone, it is set the critical factor of locating the urban distribution center near (less than 200 meters) the surroundings of this area. Moreover, in the next chapter 4.2, it will be seen how by the use of electric cargo bikes it is done a different last-mile distribution in this area that requires a direct connection with the area.

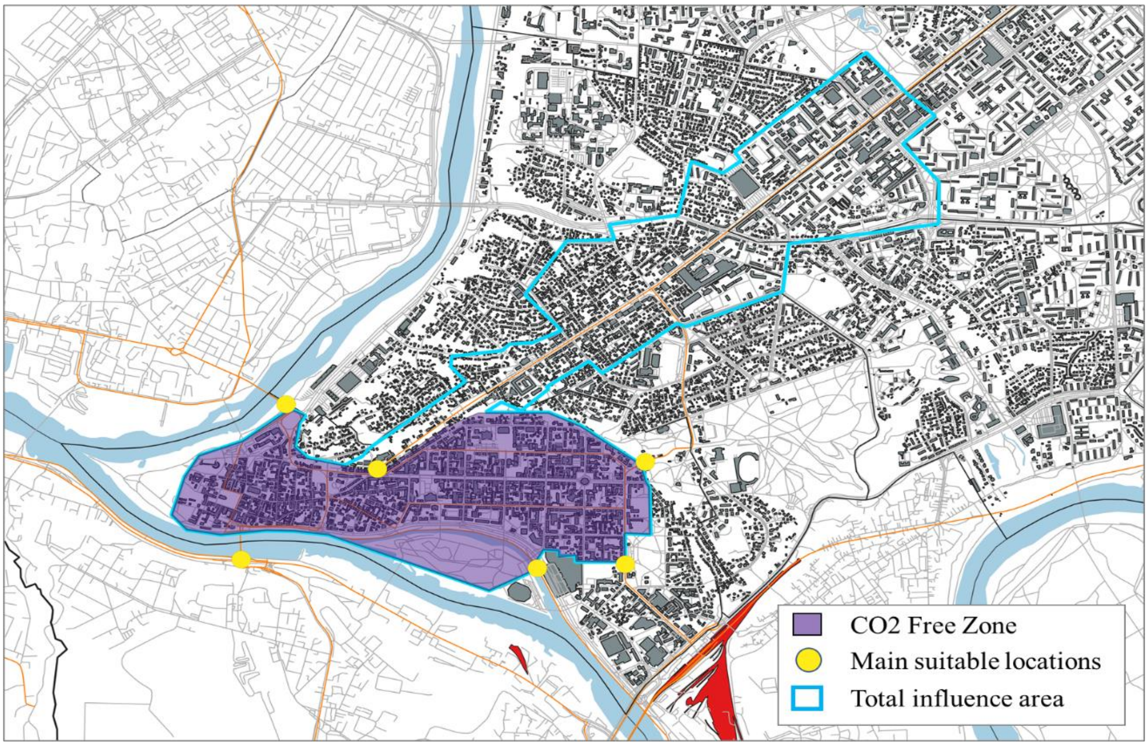

Figure 34: Resulting candidates after applying critical factors.

Applying critical factors it can be observed (see *Figure 34*) that there are 6 main suitable areas for the location of the urban distribution center.

[11] Critical factors are considered key elements strictly necessary for the development of planning. They have a binary character, taking the value 1 if they meet the requirements or 0 if not.

Step 1: Set candidate locations

The location of the urban distribution center has direct consequences on the fixed costs of the measure. For this reason, it is a very important element to be considered. This choice can make a difference in determining the viability of the distribution center. Fortunately, Kaunas has a wide variety of spaces that can accommodate this type of installation. To provide an economical solution and based on solutions adopted in other cities the following type of locations are proposed:

- **Parking lots**

  Parking lots are infrastructures that offer perfect access for vehicles. Moreover, the surface price in a parking lot is significantly lower than in other urban locations. It has been tested in cities like Barcelona where the price of urban land is very high[12].

- **Street public spaces**

  When there is strong support from the public administration, it is easier to launch this type of initiative. Sometimes, the suitable location is found in a public space where it exists a direct contact with the street. The distribution center can be located in a prefabricated module or an adapted sea container. This will reduce the installation and maintenance costs and it generates a more agile and adaptative logistic system. This type of infrastructure can be seen in the previously explained experience of Vanapedal and the city council of Barcelona (see *Figure 35*).

Figure 35: Vanapedal Urban distribution platform in Barcelona.
Source: Barcelona City Council

- **Public infrastructures or buildings**

  In a similar way to street public spaces, sometimes another good solution is the transfer of municipal equipment by the administration. It comes without saying that this type of location is also reducing the fixed cost when launching the initiative. However, sometimes it is not that easy to find a suitable space for driving this activity.

Through the analysis of the land use of Kaunas City it has been done a research to find these types of locations on the suitable locations set by the critical factors. This research has resulted in 8 initial candidates' locations that are represented in *Figure 36*.

[12] https://ecommerce-news.es/geever-nuevo-modelo-de-distribucion-urbana-de-ultima-milla-en-barcelona-77561

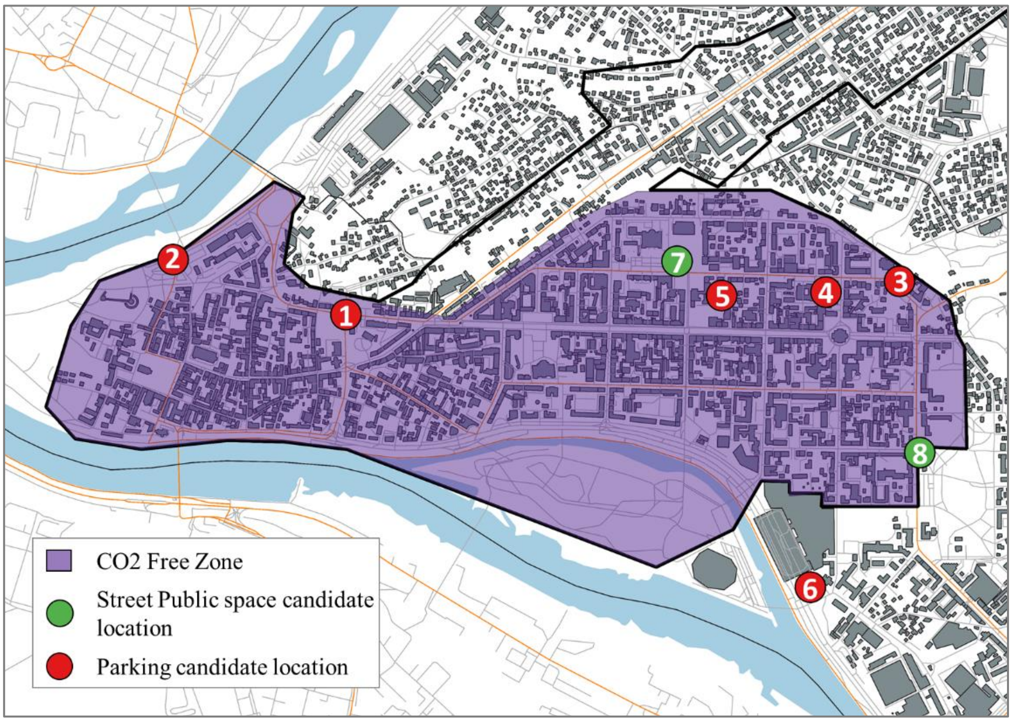

Figure 36: Initial candidates in the location problem

Step 2: Minimum requirements

In addition to the critical factors, there are also applied some minimum requirements. All those candidates who do not fit the requirements are going to be discarded. These requirements determine the minimum distance that the urban distribution center must be from the key elements of the city:

- A maximum distance of 3 km to the further point in the CO_2 Free Zone.
- A Minimum average distance of 10km to the main city transport infrastructures:
    - International Airport of Kaunas
    - Free Economic Zone
    - Palemonas Intermodal Platform
    - Kaunas central train station.

These criteria are set in order to guarantee a correct serving time inside the CO_2 Free Zone and also to find locations that are well connected with the city transport infrastructures. It is thought that these are minimum requirements for both, the correct operation of the urban distribution center and the logistic attractiveness for future partners.

Finally, after applying these minimum requirements it is seen in *Chart 13* the locations that fit the requirements. The discarded locations that are out of the requirements are locations 2, 6, and 8. Therefore, the locations that are going to be deeply analyzed are locations 1, 3, 4, 5, and 7. At this point, there is not a single criterion that will lead to a solution, there are several criteria that are involved in the selection of a suitable location. For this reason, in order to solve this problem multicriteria problem, two methodologies are going to be done; the utility function and the Brown and Gibson methodology. The project looks for more consistency by contrasting two methodologies rather than a single one.

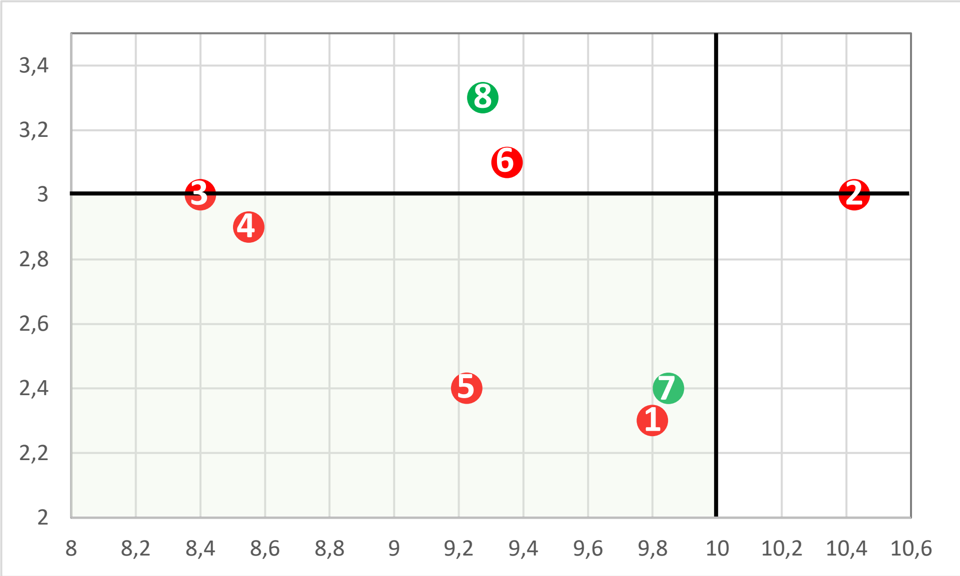

Chart 13: Minimum requirements

Step 2.1: Multicriteria solution by Utility function

When solving a multicriteria problem, the first step in the formulation of the problem is to define the objective function which is going to be the utility function. The utility function represents the satisfaction or priority that users grant to each option involved in the election process. According to this, each location is considered as a feasible election and all have its utility function. The higher the value of the utility function, the greater its suitability to be the selected location. So, the location that has the greatest utility will be the selected location. The utility function is composed of the different attributes that describe the importance value given to every factor related to the location of an urban distribution center. With this, it is stated the following function:

Definition of variables:

$$f_i = \text{the score given to the factor of the location } i$$

$$w_i = \text{the importance or priority given to the factor of the location } i$$

where,

$$i = 1, 3, 4, 5, \text{ and } 7$$

Due to the objective of the location model is to maximize the utility, the defined function is the following:

$$[MAX]\ U(f) = U\ (f1, f3, f4, f5, f7)$$

Where,

$$U(f) = \sum_{i=1}^{k} \omega_i \cdot f_i$$

In the following points are set the factors that are involved in the selection of the urban distribution center. Due to the difficulty to obtain an accurate quantitative value of these factors, the value given to some of these factors is qualitative and does not represent a real measure of the factor. Nevertheless, as all the factors are going to be evaluated under the same criteria and later compared with each other, this is not going to represent any alteration to the result.

- *Installation costs:* The cost of adapting the space to the urban logistics activity and the cost of equipment's and infrastructures.
- *Social impact:* The inconveniences caused to the resident population of the area.
- *Urban impact:* Visual disturbances and structural damages that can be caused to the location zone.
- *Operation adequacy:* Suitability of the location to operate without disturbances.
- *Security:* Adequacy of the location to keep the freight in safety conditions.
- *Proximity to border:* Proximity to the border of CO_2 Free Zone of Kaunas.
- *Space available in the area:* Capacity to increase in surface in case of need.

Considering the sustainable approach of this work, *installation costs* and *social impact* factors will represent almost the 50% of the weight that is taken into account for the multicriteria solution. Giving a relative weight (w_i) to each factor and setting different values (f_i) to the factors of each locations is defined the following Table 8.

Table 8: Given weights and factor values

Factors	w_i	**Locations**				
		1	**3**	**4**	**5**	**7**
Installation costs	0,25	4	3	2	2,5	5
Social impact	0,20	7,5	8,5	6	8	9
Urban impact	0,11	10	8	7,5	8	5
Operation adequacy	0,15	3	2	4	4	2
Security	0,07	2	2	5	5	2
Space available	0,10	8	5	7	8	5
Proximity to border	0,12	9	9	8	7	7

Using the function, it is obtained the result shown in Table 9:

Table 9: Utility function with not normalized result.

Factors	**Locations**				
	1	**3**	**4**	**5**	**7**
Installation costs	1,00	0,75	0,50	0,63	1,25
Social impact	1,50	1,70	1,20	1,60	1,60
Urban impact	1,10	0,88	0,83	0,88	0,55
Operation adequacy	0,45	0,34	0,68	0,60	0,34
Security	0,14	0,20	0,50	0,35	0,20
Space available	0,80	0,50	0,70	0,80	0,50
Proximity to border	1,08	1,08	0,96	0,84	0,84
Utility (not normalized)	6,07	5,35	5,14	5,70	5,38

For now, the methodology results into a result in which location number 1 would be the suitable option according to utility function. Nevertheless, the values given to the factors are not normalized and thus, it is possible that the results could be altered by the lack of normalization. Therefore, through the next formula it is going to be applied the normalization of factor values.

$$f_{n_i}(x) = \frac{f_i(x)}{\max(f_i(x))}$$

After the normalization, all factors values have been valued on a same scale. Applying again the utility function it results on the same solution: locating the distribution center in location 1. This location obtains the highest utility value with U (f_1) = 0,84.

Table 10: Utility function resolution through normalized factors.

Factors	w_i	**Locations**				
		1	**3**	**4**	**5**	**7**
Installation costs	0,25	0,80	0,60	0,40	0,50	1,00
Social impact	0,20	0,83	0,94	0,67	0,89	1,00
Urban impact	0,11	1,00	0,80	0,75	0,80	0,50
Operation adequacy	0,15	0,75	0,50	1,00	1,00	0,50
Security	0,07	0,40	0,40	1,00	1,00	0,40
Space available	0,10	1,00	0,63	0,88	1,00	0,63
Proximity to border	0,12	1,00	1,00	0,89	0,78	0,78
Utility		**0,84**	**0,71**	**0,73**	**0,80**	**0,76**

Step 2.2: Multicriteria solution by Brown & Gibson Methodology

Brown and Gibson methodology combines quantitative factors with other factors that are more subjective and that are valued in relative terms.

There are distinguished 3 types of factors:

- Critical factors: These factors are binary. Either they are satisfied or not. These have been applied previously in the selection of candidates.
- Objective factors: Are those factors that can be easily quantify. For this reason, in many cases these factors are considered in terms of cost. For the resolution of the present location problem, there are some costs like salaries or bicycle costs that are not going to vary because our locations are in the same city. Nevertheless, there are some others that can have different weights depending on the location. The estimation of this costs has been done considering distances and realizing hypothesis based on existing initiatives (see Appendix 1 for resolution)

Table 11: Total net present costs with 5 years project perspective (2021 to 2026).

	Total net present costs
Location 1	80.662 €
Location 3	74.343 €
Location 4	82.870 €
Location 5	84.555 €
Location 7	79.925 €

- Subjective factors: They are qualitative factors that have a deep incidence in selection of the location.
  - *Social impact:* Impact caused to citizens.
  - *Urban impact:* Impact caused to city structure and planning.
  - *Load & unload impact:* Impact caused to the traffic in the loading and unloading operations.
  - *Security problems:* Location with less potential of suffering vandalism.
  - *Space suitability problems:* Difficulties to park the vehicles, to access, etc.

Table 12: Subjective factors

	Location 1	**Location 3**	**Location 4**	**Location 5**	**Location 7**
Social impact	Medium	Medium	High	High	Medium
Urban impact	Low	Medium	Medium	Medium	High
Load & unload impact	Medium	High	Low	Low	Low
Security problems	Medium	Medium	Low	Low	Medium
Space suitability problems	Low	High	Medium	Low	High

As critical factors have already been defined, to start with the *Brown & Gibson Methodology* it is calculated the objective value of each candidate location (OF_i *, i= 1, 3, 4, 5, and 7).* Thus, to this effect it is applied the following function:

$$OF_i = \frac{1/C_{t_i}}{\sum_{i=1}^{n} 1/C_{t_i}}$$

Where Ct_i are the costs related to every objective factor or location *i.*

The total net present costs represented in Table 11 are expressing cost differentials between all locations. Whatsoever, the value of these costs is representing the total costs incurred to each location. The only costs that are considered are the ones that vary from one location to another.

Table 13: Objective factors resolution

	Total net present costs	OF_i
Location 1	82.662 €	0,1964
Location 3	76.343 €	0,2126
Location 4	82.870 €	0,1959
Location 5	84.555 €	0,1920
Location 7	79.925 €	0,2031

In second place, subjective factors SF_i *(i = 1, 3, 4, 5, and 7)* are going to be calculated. To do so, it is estimated the weighing w_j of each subjective factor by comparing them to each other. The comparison of the factors is done by pairs of factors. In this comparison it is state if one factor has more weight than other or if they are equal; values $w'_{jk} = 0$ (*j* less important than *k*) or 1 (*j* equal or more important than *k*). With this it’s defined Table 14: Factors comparison and weighing definition.Table 14, and may be seen how the weights of the factors are obtained by using the following formula:

$$w_j = \frac{\sum_{k=1}^{K} w'_{jk}}{\sum_{j=1}^{K} \sum_{k=1}^{K} w^1_{jk}}$$

Where,

j: 1, 2, 3, 4, and 5. (the factors that affect the election)

Table 14: Factors comparison and weighing definition.

	Social impact	**Urban impact**	**Load & unload impact**	**Space suitability problems**	**Security problems**	$\sum_{k=1}^{K} \omega' jk$	w_j
Social impact		1	1	1	1	4	0,364
Urban impact	0		1	1	1	3	0,273
Load & unload impact	0	1		1	1	3	0,273
Space suitability problems	0	0	0		1	1	0,091
Security problems	0	0	0	0		0	0,000
						11	

Once factors weight is defined, locations are compared taking as comparison criterion each of the factors. Therefore, 5 matrix are going to be developed in other to compare each of the locations considering on factor as the only criterion to fill in the matrix. In the same way that has been calculated w_j it is calculated R_{ij}.

$$R_{ij} = \frac{\sum_{k=1}^{K} R'_{jk}}{\sum_{j=1}^{K} \sum_{k=1}^{K} R^1_{jk}}$$

Where,

j:1, 2, 3, 4, and 5. (The factors that affect the election)
i: 1, 3, 4, 5, and 7. (The locations involved in the election)

- ***Social impact***

	Location 1	**Location 3**	**Location 4**	**Location 5**	**Location 7**	$\sum_{k=1}^{K} R' jk$	R_{ij}
Location 1		1	1	1	1	4	0,286
Location 3	1		1	1	1	4	0,286
Location 4	0	0		1	0	1	0,071
Location 5	0	0	1		0	1	0,071
Location 7	1	1	1	1		4	0,286
						14	

- ***Urban impact***

	Location 1	Location 3	Location 4	Location 5	Location 7	$\sum_{k=1}^{K} R'jk$	R_{ij}
Location 1		1	1	1	1	4	0,308
Location 3	0		1	1	1	3	0,231
Location 4	0	1		1	1	3	0,231
Location 5	0	1	1		1	3	0,231
Location 7	0	0	0	0		0	0,000
						13	

- ***Load & unload problems***

	Location 1	Location 3	Location 4	Location 5	Location 7	$\sum_{k=1}^{K} R'jk$	R_{ij}
Location 1		1	0	0	0	1	0,077
Location 3	0		0	0	0	0	0,000
Location 4	1	1		1	1	4	0,308
Location 5	1	1	1		1	4	0,308
Location 7	1	1	1	1		4	0,308
						13	

- ***Security problems***

	Location 1	Location 3	Location 4	Location 5	Location 7	$\sum_{k=1}^{K} R'jk$	R_{ij}
Location 1		1	0	0	1	2	0,143
Location 3	1		0	0	1	2	0,143
Location 4	1	1		1	1	4	0,286
Location 5	1	1	1		1	4	0,286
Location 7	1	1	0	0		2	0,143
						14	

- ***Space suitability problems***

	Location 1	Location 3	Location 4	Location 5	Location 7	$\sum_{k=1}^{K} R'jk$	R_{ij}
Location 1		1	1	1	1	4	0,333
Location 3	0		0	0	1	1	0,083
Location 4	0	1		0	1	2	0,167
Location 5	1	1	1		1	4	0,333
Location 7	0	1	0	0		1	0,083
						12	

Finally, to obtain the value of the subjective factors SF_i it is necessary to combine for each location the weight w_i and the assigned R_i :

$$SF_i = \sum_{j=1}^{k} \omega_j \cdot R_{i_j}$$

With this, it is represented Table 15, where the subjective factors are represented.

Table 15: Subjective factors calculation.

	Location 1	Location 3	Location 4	Location 5	Location 7	w_j
Social impact	0,286	0,286	0,071	0,071	0,286	0,364
Urban impact	0,308	0,231	0,231	0,231	0,000	0,273
Load & unload impact	0,077	0,000	0,309	0,309	0,308	0,273
Space suitability problems	0,143	0,143	0,286	0,286	0,143	0,091
Security problems	0,333	0,083	0,167	0,083	0,083	0,000
SF_i	**0,222**	**0,180**	**0,199**	**0,199**	**0,201**	

With the results obtained, it is seen how every location obtains a suitability value depending on both, the objective, and the subjective factors.

Table 16: Factors values

	OFi	SFi
Location 1	0,1964	0,222
Location 3	0,2126	0,180
Location 4	0,1959	0,199
Location 5	0,1920	0,199
Location 7	0,2031	0,201

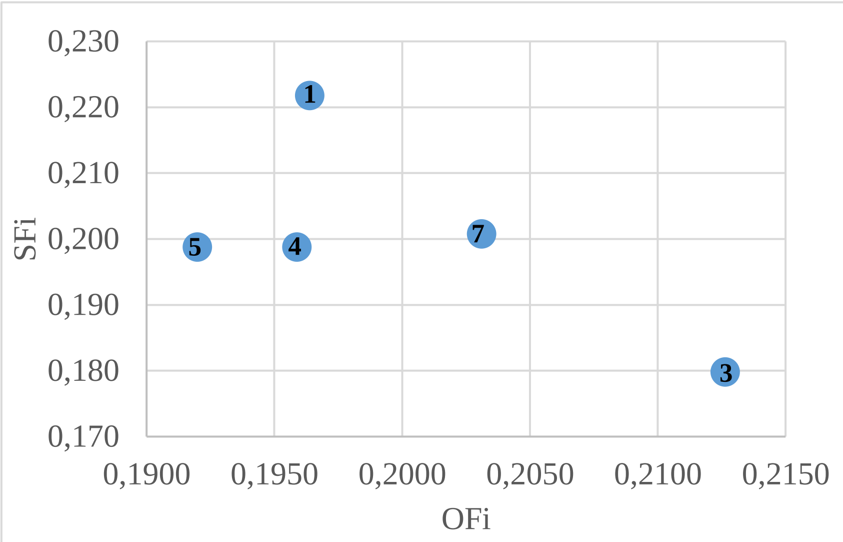

Chart 14: Objective and subjective factors representation.

Nevertheless, with the chart representation it is difficult to state a solution to the problem. Moreover, the importance given to every type of factor can change the result of the problem. To understand stability of the resulting solution it is done a sensibility analysis. In this it will be seen how the result changes depending on the given priority to each type of factors; objective or subjective. To do so, it is used the following formula:

$$IL_i = \alpha \cdot OF_i + (1 - \alpha) \cdot SF_i$$

Where,

α is a factor that represents the priority given to each type of factor.

As it is been done for the Utility function, during this process it is given a high priority to *economic costs* and *Social impact*. Thus, to obtain a solution in the present problem, it is fixed the reference α of 0,45. This will give a greater weight of 0,55 to SF_i and a weight of 0,45 to OF_i. However, it is going to do a calculation giving different values to α in order to see how consistent is the resulting solution.

Table 17: Sensibility analysis

α	Location 1	Location 3	Location 4	Location 5	Location 7
0,1	0,21924	0,18310	0,19851	0,19812	0,20103
0,2	0,21670	0,18638	0,19822	0,19744	0,20126
0,3	0,21416	0,18967	0,19793	0,19676	0,20149
0,4	0,21162	0,19295	0,19764	0,19607	0,20172
0,45	0,21035	0,19459	0,19749	0,19573	0,20184
0,5	0,20908	0,19623	0,19734	0,19539	0,20195
0,6	0,20654	0,19951	0,19705	0,19471	0,20218
0,7	0,20400	0,20279	0,19676	0,19403	0,20241
0,8	0,20146	0,20607	0,19647	0,19335	0,20265
0,9	0,19892	0,20936	0,19618	0,19267	0,20288

As it is seen, the resulting value is stable and has enough consistency to change (only) when 0,8 α value is reached. With this, it can be stated that the resulting location from the *Brown & Gibson methodology* is the Location 1.

4.1.6. Resulting implementation

To locate the urban distribution center it has been solved a multicriteria process following clear steps. In the first term, some critical criteria have been fixed to delimit the possible candidates. Secondly, from the different possible candidates that have been found, it has been stated some minimum requirements that the locations should have. With this it resulted in 5 possible candidates that have been evaluated through 2 different multicriteria methodologies: Utility function and Brown & Gibson.

Finally, after comparing the result of both methodologies, it is set as a location for the urban distribution center the candidate *Location 1*. This location is at the crossroads between the street Šv. Gertrūdos and Gimnazijos. In this location it can be found different suitable candidates to locate the urban distribution center.

Figure 37: Available spaces in Location 1 to locate the urban distribution center.
Source: Google Maps

In short, any of these locations could work to develop the urban distribution center. The election of one spot or another would depend on urbanistic planning and availability, which won't be discussed in this project. Finally, it may be seen in Appendix 2, the final location and distribution of the system.

4.2. Implementation of a last-mile distribution system by electric bicycles

During the present project, it has been proved the difficulties and problems that last-mile distribution of goods is experiencing in cities and urban areas. The present measure aims to be a solution for the urban distribution center that has been developed in the previous section 4.1.

4.2.1. Objective

The present measure aims to develop a logistic system for the operation of the urban distribution center created in section 4.1. The main purpose of this implementation is to generate a logistic system driven by electric bicycles.

To do so, some estimations of demand are done to generate the most realistic landscape for the implementation. With this it is expected to come up with a most efficient logistic system that at the same time could establish a more sustainable logistic model in the city of Kaunas.

In short, different operation variables and restrictions are going to be considered to set the logistic system. It is expected to identify the optimum number of routes, employees, and vehicles needed to operate the system.

4.2.2. Location

The serving area of the urban distribution center is composed of two different areas: the CO_2 Free Zone and the zone of Savanorių pr. street. These two areas are well-identified in *Figure 33*. Both areas have different characteristics; the CO_2 Free Zone has more pedestrian and cycleways while the other is mainly composed of the fast way of Savanorių pr.

To implement a logistic system driven by electric bicycles it is thought that the CO_2 Free Zone would represent a more favorable scenario. Besides, the utilization of bicycles fits perfectly with the future city council plans for the area. Thus, it shows the zone that will be served by electric cargo bicycles.

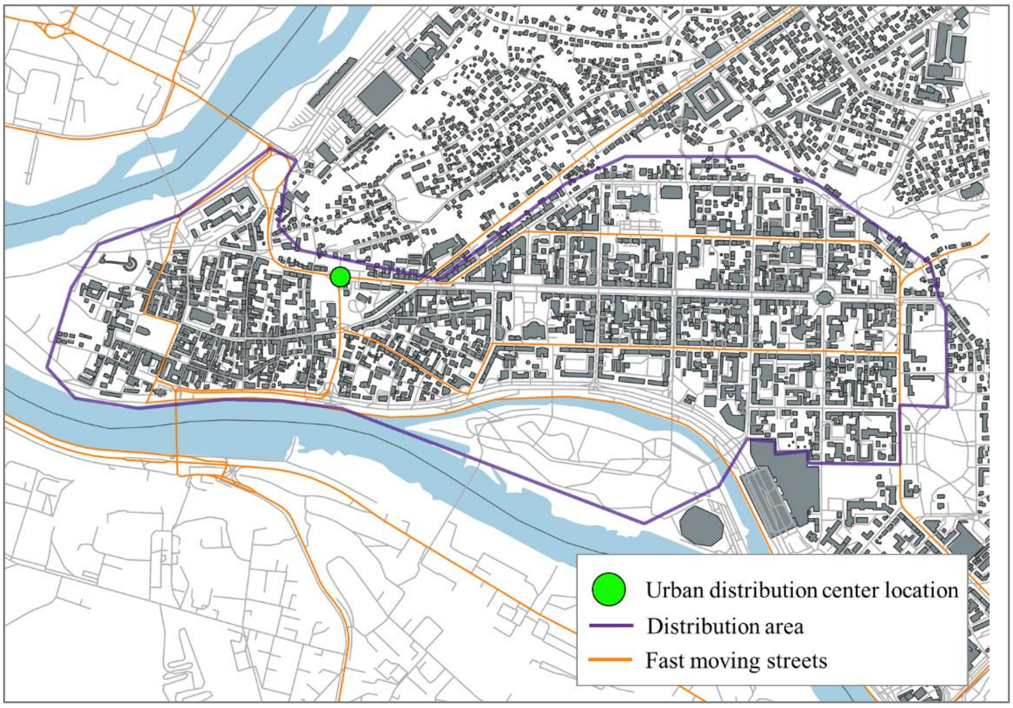

Figure 38: Serving area for the cargo bicycles distribution system.

4.2.3. Operation

Some has been previously explained in subsection 4.1.2 about the operation of the urban distribution center. Nevertheless, it is important to consider the operating factors that will affect on the system. To do so, it has been considered the values from two Spanish projects; Txita from Bilbao and Vanapedal from Barcelona (Health, environment, and labor Sindical Institute of Spain., November 2012).

- **Demand:**

In the experiences of Bilbao and Barcelona, with an approximate service area of 3 km^2, the number of packages delivered every day is 200 and 234 respectively. Taking into account that the covered surface of the present distribution hub is around 2 km^2 it is supposed to be less demand. Nevertheless, the project sets as an objective to achieve a capacity of 180 packages/day.

Moreover, because the capacity of the bicycles is limited, henceforth, the demand will be treated in terms of volume. Volumetric capacity will be the most limited fact in terms of capacity, because the weight capacity is way bigger than the volumetric one.

Then with the data provided from Txita bikes is done the following hypothesis:

- If they have 6 employees and each employee does 7 trips/day on average, there is a total average of 42 trips each day. If the maximum capacity of a bicycle is 1,5 m^3, then the average volume transported every day is 63 m^3, what it traduces in 0,315 m^3/package if it is considered that every day an average of 200 packages are delivered.

Thus, the total average volumetric capacity of the present distribution center is about 56,7 m^3/day. This value will be rounded to 60 m^3/day to add some safety space in each travel.

- **Time windows:**

As has been explained in other sections, it exists different time windows for each economic activity sector. Due to this situation, the different time windows of companies are spread all along the day. It is estimated that the distribution through cargo bicycles is going to be operating from 6.00 am to 9 pm. To organize in some way the demand distribution in function of time, it has been realized the following groups of demand:

- GROUP A: Possibility of delivery at any time from 6:00 am to 9 pm.

  Examples: Pick up points, convenience stores, pharmacies, etc.

- GROUP B: Necessity of delivery at the first hours of the days 6 am to 10 am.

  Examples: Grocery stores, alimentation stores, Hotel and catering industry, etc.

- GROUP C: Possibility of delivery during workday hours from 8 am to 5 pm.

  Examples: Offices, shops, schools, workshops, etc.

- GROUP D: Preference of delivery after workday hours during the afternoon from 5 pm to 9 pm.

  Examples: Households, florist, etc.

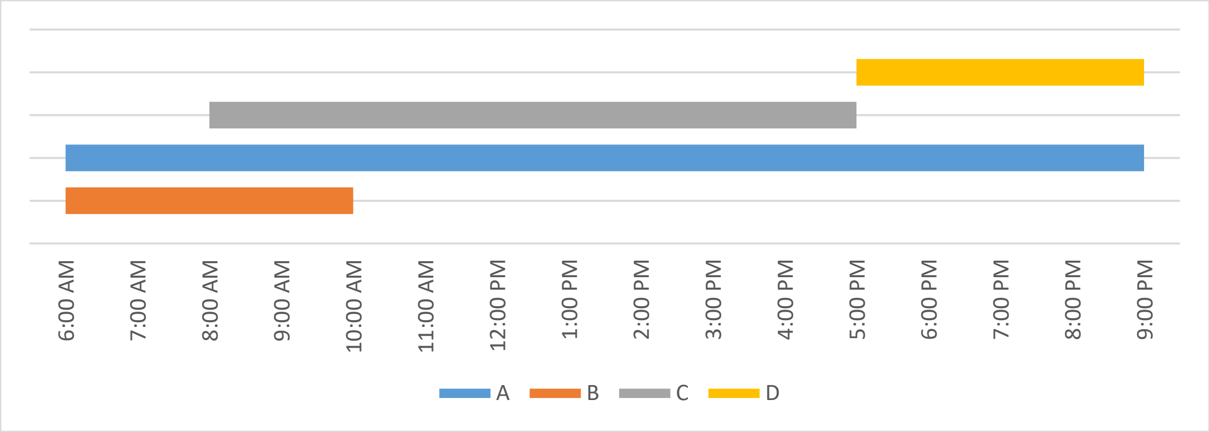

Chart 15: Daily time window scheduled to deliver to each group of customers.

- **Demand location:**

The demand of the urban distribution system is going to be spread inside the service area. This might probably change and move over time since every type of customer has different supply needs. Nevertheless, to model a solution it is necessary to locate the demand in some way that would represent a real situation. Considering the different demand time window groups, it has been done the following approximation of location customers that the distribution hub could have. The locations have been chosen selecting real establishment and taking into account the density parameters analyzed in section *3.3.1 Demand sectors*.

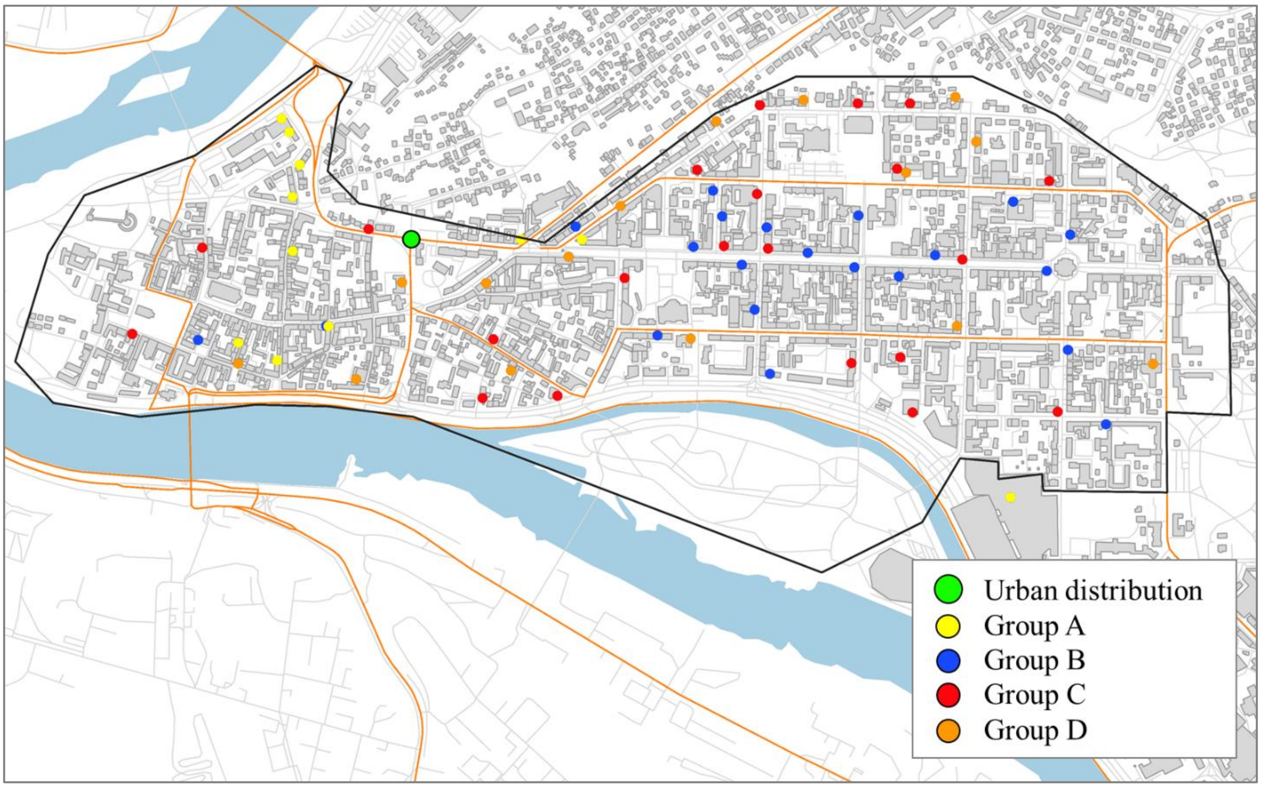

Figure 39: Location of different groups of demand.

- **Loading capacity:**

The cargo cabin dimensions used for the projects in Bilbao and Barcelona, have a volumetric capacity of 1,5 m^3, and a weight capacity of 180 kg. It is supposed that the cargo bikes used in the present project will have the same capacity.

Considering this capacity and that every day demand is 60 m^3, the total number of minimum routes is of 40 routes/day. If it is taken into account that every route would have an approximate duration of 1,5 hours[13], each cargo bicycle has a maximum capacity of 10 travels during the 15 hours of operation. Thus, to achieve the optimum number of 40 routes/day, it will be necessary to have 4 operating vehicles.

- **Autonomy:**

The battery autonomy has a limit of 5 hours of operation. Besides, the time for a full charge is estimated in 3,5 hours.

- **Workday limit:**

In the decision process of creating the routes it will be decided the number of employees needed to develop drive the bicycles. However, as it is a physical activity, it is considered that the workday limit for the employees is going to be of 7 hours a day.

4.2.4. Vehicle routing problem

Step 1: Definition of the problem

To generate a logistic system for the urban distribution of goods by electric cargo bikes, it is going to develop the necessary routes to fulfill customers supply needs. The vehicle routing problem consists in a combinatorial optimization and integer programming problem which finds the optimal routes that must traverse a fleet of vehicles to deliver a given set of customers. To do so, demand is going to be spread uniformly in each group:

Table 18: Daily demand for each demand group.

	GROUP A	GROUP B	GROUP C	GROUP D	TOTAL
Number of Clients	9	21	21	15	66
Daily demand	15 m^3	15 m^3	15 m^3	15 m^3	60 m^3

Inside each group, demand is going to be distributed uniformly through the time, as shown in Table 19. With this it is obtained different demands needs for each of the delivery moments. The times shown are the exact time where the fleet of vehicles is living the distribution center to supply customers. As it is supposed to be a total of 4 vehicles, with a total capacity of 6 m^3, and the demand is about 60 m^3, there will be a total of 10 delivery moments during the day.

[13] The estimation of time done for each of the routes, is done considering the load of the vehicles.

Table 19: Demand distribution in each of the 10 daily deliveries. (units in m^3)
* This row shows the number of vehicles need for the Total expressed volume.

	AM				PM					
	6	**7:30**	**9**	**10:30**	**12**	**1:30**	**3**	**4:30**	**6**	**7:30**
A	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5	1,5
B	5	5	5							
C		2,5	2,5	2,5	2,5	2,5	2,5			
D								5	5	5
Total	6,5	9	9	4	4	4	4	6,5	6,5	6,5
Vehicles*	5	6	6	3	3	3	3	5	5	5

As may be seen in Table 19, the confluence of different demand groups in the same delivery moment generates certain seasonality in the delivery of goods, generating picks of demand at the beginning and the end of the day. This is a situation that is preferably avoidable because it forces the company to have more resources just for certain hours. In the table, in red is shown when the volume exceeds the distribution capacity, and in yellow when the distribution center is operating under its capacity. To achieve higher efficiency is better to have a more constant and continuous demand that could lead to a better optimization of the resources.

Consequently, it is done a balancing of the different deliveries to distribute them in other hours where there is free capacity. This redistribution of the demand has been done for the group A and B. These groups allow more flexibility in the deliveries because they represent wider time windows and, in most cases, non-perishable products that do not require very short lead times.

In real-time experience, this balancing would require the negotiation and agreement of the customers. However, it is thought that the balancing of the freight would not suppose major problems for service quality.

Table 20: Balancing of volume deliveries for each group and delivery moment.
* This row shows the number of vehicles need for the Total expressed volume.

	AM				PM					
	6	**7:30**	**9**	**10:30**	**12**	**1:30**	**3**	**4:30**	**6**	**7:30**
A	1			2,75	2,75	2,75	2,75	1	1	1
B	5	5	5							
C		1	1	3,25	3,25	3,25	3,25			
D								5	5	5
Total	6	6	6	6	6	6	6	6	6	6
Vehicles*	4	4	4	4	4	4	4	4	4	4

At the end of these step it has been defined each of the different groups of delivery that would be during a day.

- During 6 am to 7:30 am: Group A and B.
- During 7:30 am to 10:30 am: Group B and C.
- During 10:30 am to 4:30 pm: Group A and C.
- During 4:30 pm to 9 pm: Group A and D.

For each of these groups of routes it will be required to find the optimal routes to serve the demand during the specified time for each group.

<u>Step 2: Problem statement</u>

Variables:

- (i, j) are every pair of locations where $i, j \in N$ and $i \neq j$
- n is the number of locations
- N is set of customers, with $N = \{1, 3, \ldots, n\}$
- A is set of arcs, with $A = \{(i, j) \in V^2 : i = j\}$
- d_{ij} is distance of travel to locations $(i, j) \in A$ $(d_{ij} = d_{ji})$
- x_{ij} is a binary variable that has value *1* if the arc (i, j) is considered as part of the solution and *0* otherwise.
- Q is the vehicle capacity
- q_i is the demand that must be delivered to location $i \in N$
- u_i is an additional continuous variable which represents the load left in the vehicle after visiting customer i and q_i is the demand of customer i.

Objective function:

$$MIN \sum_{i,j \in A} d_{ij} \cdot x_{ij} \tag{2.1}$$

Subjected to:

$$\sum_{j \in V \; j \neq i} x_{ij} = 1 \quad i \in N \tag{2.2}$$

$$\sum_{i \in V \; i \neq j} x_{i_j} = 1 \quad j \in N \tag{2.3}$$

$$\text{if } x_{ij} = 1 \rightarrow u_i + q_j = u_j \qquad i, j \in A : j \neq 0, i \neq 0 \tag{2.4}$$

$$q_j \leq u_j \leq Q \qquad I \in N \tag{2.5}$$

$$x_{ij} \in \{0, 1\} \qquad i, j \in A \tag{2.6}$$

The function 2.1 is minimizing the distance of the resulting solution. By minimizing the distance, it is found the solution with less time and thus, the solution that implies a lower operating cost. Restrictions 2.2 and 2.3 guarantees that for each location there is only one arc entering to the location and one arc living the location. With restriction 2.4 it is set that if an arc is used, then the sum of what the vehicle lives in the location (that is negative) and what the vehicle carries before entering is equal to what the vehicle carries when living the location. In restriction 2.5 is declared that the demand of the locations is always going to be equal or lower than the freight unloaded in one location and this last one is going to be inferior to the vehicle capacity. Finally, in 2.6 it is set that the binary variable x_{ij} can just have the values 1 or 0.

Step 3: Clarke and wright algorithm

Clarke and wright algorithm is a methodology to solve the vehicle routing problem through the use of a "greedy" approximation known as the saving algorithms. To understand this process, it is going to be explained with the 6 am to 7:30 am routes as an example. To see the calculations of all the routes, see Appendix 3. Routes calculation: Clarke and Wright algorithm..

Before solving the algorithm, it is important to state that the algorithm has been solved trying to minimize 2 aspects. Firstly, it has been minimized the distances travelled by the different vehicles. And in second place, it has been minimized the number of clients split in more than one vehicle. Thus, it has been tried that every customer will be served always by the same vehicle in the same travel.

0. Presenting the data of the problem.

Demand: To solve the present problem, it has been simplified the number of locations in which it is required to delivery freight. The simplification of clients' locations has been done in a way that one location of the problem represents more than one location in the reality. The simplification process may be seen in Appendix 4.

Thus, in the resolution of this problem it is not being worked with the locations seen in Figure 39, but a simplification of all of them. By reducing the number of locations, it is more affordable to solve this problem and the obtained solution would be a simplification of reality, but a good approximation of a possible real scenario.

Table 21: Demand from 6 am and 7:30 am.

0	0
1	0,455
2	0,273
3	0,182
4	0,091
5	0,476
6	0,952
7	0,952
8	1,429
9	0,714
10	0,476

Distance matrix: represents the distance between each of the points, being 0 the depot.

Table 22: Distance matrix for simplified locations of 6 am to 7:30 am.

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0	0	351	395	365	1614	442	759	897	1117	1538	1664
1	351	0	401	696	1960	402	1056	1239	1424	1838	2000
2	395	401	0	719	1871	61	1126	1191	1466	1889	1957
3	365	696	719	0	1268	775	407	545	754	1177	1304
4	1614	1960	1871	1268	0	1931	1012	724	723	663	237
5	442	402	61	775	1931	0	1182	1252	1524	1947	2018
6	759	1056	1126	407	1012	1182	0	362	370	784	987
7	897	1239	1191	545	724	1252	362	0	378	752	770
8	1117	1424	1466	754	723	1524	370	378	0	423	646
9	1538	1838	1889	1177	663	1947	784	752	423	0	463
10	1664	2000	1957	1304	237	2018	987	770	646	463	0

1. Begin with an unfeasible solution in which every customer is supplied individually by a separate vehicle.

Table 23: Unfeasible solution (1 vehicle/location)

	O	D	O	D	TOTAL
Q1	0	1	1	0	**0,455**
d1	0	351	0	351	**701**
Q2	0	2	2	0	**0,273**
d2		395		395	**790**
Q3	0	3	3	0	**0,182**
d3	0	365		365	**731**
Q4	0	4	4	0	**0,091**
d4		1614		1614	**3228**
Q5	0	5	5	0	**0,476**
d5		442		442	**884**
Q6	0	6	6	0	**0,952**
d6		759		759	**1517**
Q7	0	7	7	0	**0,952**
d7		897		897	**1795**
Q8	0	8	8	0	**1,429**
d8		1117		1117	**2233**
Q9	0	9	9	0	**0,714**
d9		1538		1538	**3077**
Q10	0	10	10	0	**0,476**
d10		1664		1664	**3329**

2. Combine any two of these single customer routes to use one less vehicle and reduce total distance:

- The distance of servicing customers i and j individually by two vehicles is: $d_{0i} + d_{i0} + d_{0j} + d_{j0}$
- The distance of one vehicle serving *i* and *j* on the same route is: $d_{0i} + d_{ij} + d_{j0}$
- Combining i and j result in cost savings of sij = di0 + d0j - dij

Table 24: Combining pairs of routes

		O	D	O	D	O	D	TOTAL	
Q1	Q2	0	1	1	2	2	0	0,727	Savings
d1	d2	0	351		401	0	395	1147	344
Q1	Q3	0	1	1	3	3	0	0,636	Savings
d1	d3	0	351		696	0	365	1412	20
Q1	Q4	0	1	1	4	4	0	0,545	Savings
d1	d4	0	351		1960	0	1614	3925	5
Q1	Q5	0	1	1	5	5	0	0,931	Savings
d1	d5	0	351		402	0	442	1195	391
Q1	Q6	0	1	1	6	6	0	1,407	Savings
d1	d6	0	351		1056	0	759	2165	53
Q1	Q7	0	1	1	7	7	0	1,407	Savings
d1	d7	0	351		1239	0	897	2487	9
Q1	Q8	0	1	1	8	8	0	1,883	X
d1	d8	0	351		1424	0	1117	2891	X
Q1	Q9	0	1	1	9	9	0	1,169	Savings
d1	d9	0	351		1838	0	1538	3727	50
Q1	Q10	0	1	1	10	10	0	0,931	Savings
d1	d10	0	351		2000	0	1664	4015	15

3. Select the arc (i, j) with maximum saving subject to the requirement that the combined routes is feasible (does not exceed vehicle capacity).

In table Table 24 it is shown how to add to route of vehicle 1 another destination. To do so, it is combined with the vehicle 1 route each of other locations. With it is calculated the savings generated by the combination of routes. The calculation of the savings compares the distance traveled when the routes are done individually and the distance d_i travelled when they are combined. Besides, in Q_i is done the sum of demand to see if the vehicle has capacity to deliver to the set of locations.

For locations 1 and 5 exists higher saving than in the other locations. Then the route one will be composed by locations 1 and 5. On the other hand, for locations 1 and 8, the capacity of the vehicle is exceeded and thus, it is not a feasible solution. The split of demand of one customer will be done when there is no other alternative to assign.

4. Repeat the process until the number of routes is reduced to: $\mathbf{K} = \left| \frac{\sum_{j \in v} w_j}{C} \right|$

Again, the process is repeated till all the demands are satisfied.

			O	D	O	D	O	D	O	D	TOTAL	
Q1	Q5	Q2	0	1	1	5	5	2	2	0	1,203	Savings
d1	d5	d2	0	351		402		61	0	395	1208	776
Q1	Q5	Q3	0	1	1	5	5	3	3	0	1,113	Savings
d1	d5	d3	0	351		402		775	0	365	1893	32
Q1	Q5	Q4	0	1	1	5	5	4	4	0	1,022	Savings
d1	d5	d4	0	351		402		1931	0	1614	4298	125
Q1	Q5	Q6	0	1	1	5	5	6	6	0	1,883	X
d1	d5	d6	0	351		402		1182	0	759	2693	X
Q1	Q5	Q7	0	1	1	5	5	7	7	0	1,883	X
d1	d5	d7	0	351		402		1252	0	897	2902	X
Q1	Q5	Q9	0	1	1	5	5	9	9	0	1,645	X
d1	d5	d9	0	351		402		1947	0	1538	4238	X
Q1	Q5	Q10	0	1	1	5	5	10	10	0	1,407	Savings
d1	d5	d10	0	351		402		402	0	1664	2818	1705

Applying this algorithm for each of the groups it has been find the following routes for each of the different moments of the day:

Table 25: Routes group 1 from 6 am to 7:30

	STOP 1	STOP 2	STOP 3	STOP 4	Total
Vehicle 1	1	5	10	4	d1= 3.005
Capacity 1	0,45	0,48	0,48	0,09	1,50
Vehicle 2	2	9	3	8	d2= 5.332
Capacity 2	0,27	0,71	0,18	0,33	1,50
Vehicle 3	7	8	-	-	d3= 2.392
Capacity 3	0,95	0,55			1,50
Vehicle 4	6	8	-	-	d4= 2.245
Capacity 4	0,95	0,55			1,50

Table 26: Routes group 2 from 7:30 am to 10:30 am.

	STOP 1	STOP 2	STOP 3	STOP 4	STOP 5	Total
Vehicle 1	5	11	12	10	14	d1= 4.014
Capacity 1	0,48	0,14	0,19	0,48	0,14	1,4
Vehicle 2	6	13	15	-	-	d2= 3.461
Capacity R2	0,95	0,24	0,29			1,5
Vehicle 3	8	9	-	-	-	d3= 3.078
Capacity R3	1,43	0,07				1,5
Vehicle 4	9	7	-	-	-	d4= 3.188
Capacity R4	0,64	0,95				1,6

Table 27: Routes group 3 from 10:30 am to 4:30 pm

	STOP 1	STOP 2	STOP 3	STOP 4	Total
Vehicle 1	1	11	-	-	d1= 1.487
Capacity 1	1,250	0,250			1,5
Vehicle 2	2	11	4	14	d2= 4.603
Capacity 2	0,75	0,21	0,25	0,29	1,5
Vehicle 3	3	14	13	-	d3= 1.931
Capacity 3	0,50	0,18	0,773809524		1,5
Vehicle 4	12	15	-	-	d4= 3.006
Capacity 4	0,62	0,93			1,5

Table 28: Routes group 4 from 4:30 pm to 9 pm.

	STOP 1	STOP 2	STOP 3	STOP 4	STOP 5	Total
Vehicle 1	1	2	4	3	18	d1= 6.949
Capacity 1	0,455	0,273	0,091	0,182	0,500	1,5
Vehicle 2	16	19	-	-	-	d2= 1.450
Capacity 2	1,33	0,17				1,5
Vehicle 3	17	18	-	-	-	d3= 3.727
Capacity 3	1,33	0,17				1,5
Vehicle 4	18	19	-	-	-	d4= 3.768
Capacity 4	0,33	1,17				1,5

4.2.5. Resulting implementation

The developed measure has been done with different hypotheses and approximations that generated the most realistic landscape. As it is been said, the hypothesis and approximations have been done focusing on other cities implementations.

After defining the different variables involved in the vehicle routing problem, it has been found a feasible solution for the problem with the Clarke and Wright algorithm. With this, it has been obtained a solution. Because it has been considered better to set a fixed number of 4 vehicles, the obtained solution is not the most optimum in terms of traveled distance. Nevertheless, it is optimum considering that it was wanted to fix the number of vehicles and to minimize the number of split-client demand.

Table 29: Routes distribution for each vehicle and moment of the day.

	From 6 am to 7:30 am	From 7:30 am to 10:30 am	From 10:30 am to 4:30 pm	From 4:30 pm to 9 pm
Vehicle 1	1-5-10-4	5-11-12-10-14	1-11	1-2-4-3-18
Vehicle 2	2-9-3-8	6-13-15	2-11-4-14	16-19
Vehicle 3	7-8	8-9	3-14-13	17-18
Vehicle 4	6-8	9-7	12-15	18-19

However, despite it is not necessary to have more than 4 cargo bicycles, it is recommended to add a 5th bicycle to have more operative flexibility. As demand is not constant and the calculations have been done in average terms, it is considered appropriate to do so. The 5th bicycle could be one with less freight capacity and a faster average speed. This will reduce the bicycle cost and make our operation system more agile. Besides, all the operatives can be driven by 4 carriers.

To finish, Figure 40 shows the carriers routes distribution. It has been developed setting an average speed of 10 km/h and an average unloading time of 10 minutes for each stop. As may be seen there will be 4 carriers that will perform the deliveries to all customers. It has been tried to balance the cycling time of each of the carriers and the working time for each cycle.

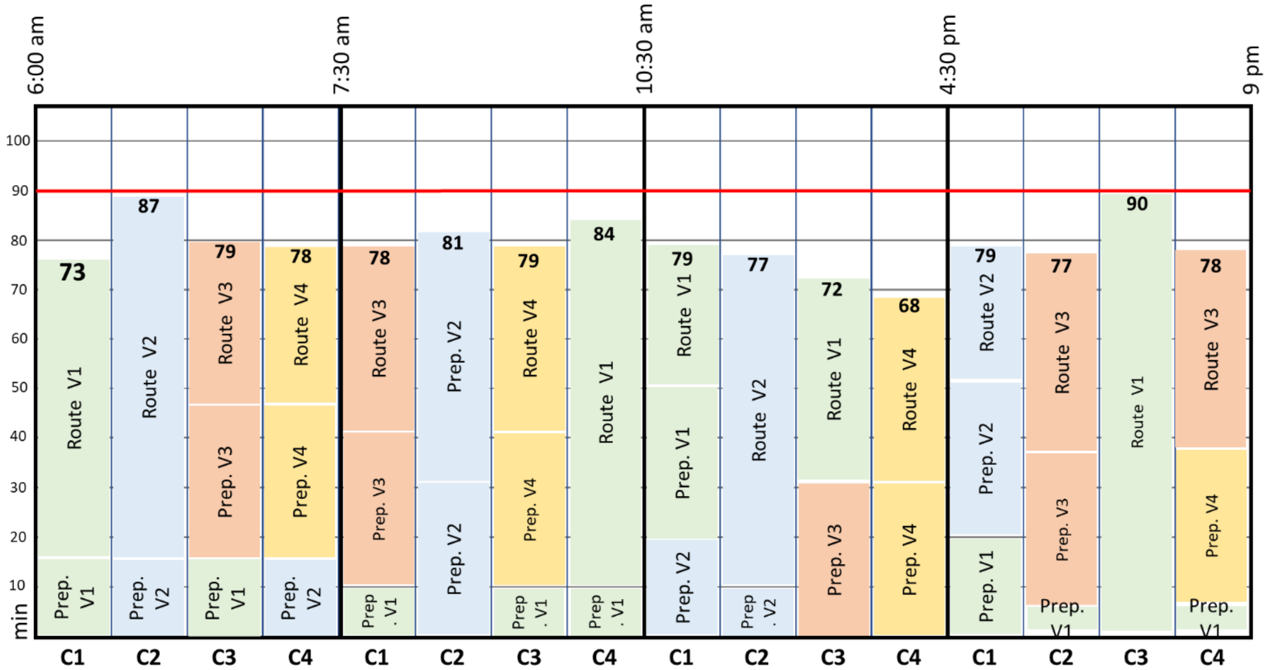

Figure 40: Carriers work distribution.

See Appendix 5. to see the routes trajectories for everyday moment.

4.3. Tracking Indicators and Expected Results

As important as developing good planning is to build a monitoring and tracking over the implementation of the urban distribution center. Having control over the development of the urban distribution center will provide enough data to drive a proper evaluation of the implementation process and correct those things that need to improve.

For the present measure, it is proposed the following indicators:

- **Evolution of monthly deliveries:** To have a general view of the volume of freight that has been manipulated in the distribution center. Also, it is a good way to identify the seasonality of the business and if there is an increase in demand. The present project has dimensioned the urban distribution center for a total of 180 deliveries/day what is traduced in an approximate of 900 deliveries/month. This is considered a good goal to start.
- **Number of deliveries per trip and day:** It is a value that will give a view on the efficiency of the routes. At the end of the day, what is pursued is that all vehicles realize a similar number of deliveries. It goes without saying that it is wanted to have the maximum number of deliveries for each trip and vehicle. As soon as the distribution center will start working it will be seen which are the top values that the operative can reach. For now, the set design fixes the following values:

	Deliveries/trip*day
Vehicle 1	3,7
Vehicle 2	3,2
Vehicle 3	2,4
Vehicle 4	2
Total	2,83

- **Number of deliveries per kilometer:** This indicator will tell us the performance of the routes system. If the number of deliveries per kilometer is lower, it would be that it is needed to travel long distances to reach clients. This could mean 2 things; or the urban distribution center is not well located or maybe, the design of the routes is not optimum. To set a goal, the cited Vanapedal experience reached a total of 4 deliveries/km.

Conclusions

1. The present project has focused on analyzing the present and future problematics related to the logistics in Kaunas, the different stakeholders related to the logistics activities, the plans and priorities established by different levels of public administration and finally, it has proposed two related measures to contribute to the improvement of the described scenario.

2. The success of the proposed measures mainly remains in a proper collaboration between the private and the public agents. On one hand, the administration must put all its efforts to make the solution available and economically viable. On the other hand, the private sector must trust the plans and measures applied by the public administration. It has been demonstrated with the experiences developed in other cities that the collaboration of both parties entails a global benefit.

3. It goes without saying, that the introduction of these measures would suppose a first initial step to establish a progressive implementation process of the CO_2 Free Zone. The project, by its nature, proposes measures for the short term, which make sense with long-term planning. Also, the solution developed, can be duplicated, and established in other parts of the city as soon as the model becomes stable.

4. The proposed measures cannot be a single action in the city logistics planning. It is needed for a complete action plan that these measures are complemented with other measures. Besides, the present measures are focused on the official mobility plans that are in the public domain. It will be interesting to contrast the measures with the urbanistic plans and future development plans that are not yet approved.

5. In short, the present project has shown that there are feasible solutions to develop sustainable models for the logistic activities in the urban areas. It has been demonstrated how Kaunas has the perfect environment in order to become an important logistic center for Lithuania and the Baltic states. The solutions proposed in this project are feasible, can be measured, and establish a new collaborative scenario involving all city stakeholders. Thus, it is strongly believed that this type of solution will be starting path to build the European cities of tomorrow.

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5. Appendices

5.1. Appendix 1. Objective Function calculation

First of to find the Objective Function values, the following factors are taken into account:

- Cost of space adequacy: It will be higher for those locations that have a difficult access and lower for those infrastructures that have a very easy access.
- Added cost associated to distance: Added cost related to the distance to key infrastructures. To calculate this cost it has been multiplied separately the km to TEN-T corridors and the distance to main infrastructures with the factor of 1,052 €/km. (https://www.fomento.es/MFOM.CP.Web/handlers/pdfhandler.ashx?idpub=TTW103).
- Leasing charge: Estimated cost of leasing the public space. It has been though to put a higher cost in does spaces that are used for a higher group of people.

It is thought that these factors are the only think that can change in terms of costs from one location to another. Thus, it has been calculated the in total actualized costs that the investment could have in each of the locations.

Location 1 – Public parking with direct street contact.

	2021	2022	2023	2024	2025	2026
Space adequacy	14.000 €					
Initial inversion	14.000 €					
To main infraestructures		7.800 €	7.800 €	7.800 €	7.800 €	7.800 €
To TEN-T roads		7.300 €	7.300 €	7.300 €	7.300 €	7.300 €
Added cost associated to distance		15.100 €	15.100 €	15.100 €	15.100 €	15.100 €
Leasing charge		1.200 €	1.200 €	1.200 €	1.200 €	1.200 €
Total Costs	14.000 €	16.300 €	16.300 €	16.300 €	16.300 €	16.300 €
Total Actualized Costs (TAC)	14.000 €	15.377 €	14.507 €	13.686 €	12.911 €	12.180 €

TCA	82.662 €

Location 3 – Public parking with direct street contact.

	2021	2022	2023	2024	2025	2026
Space adequacy	14.000 €					
Initial inversion	14.000 €					
To main infraestructures		6.700 €	6.700 €	6.700 €	6.700 €	6.700 €
To TEN-T roads		6.900 €	6.900 €	6.900 €	6.900 €	6.900 €
Added cost associated to distance		13.600 €	13.600 €	13.600 €	13.600 €	13.600 €
Leasing charge		1.200 €	1.200 €	1.200 €	1.200 €	1.200 €
Total Costs	14.000 €	14.800 €	14.800 €	14.800 €	14.800 €	14.800 €
Total Actualized Costs (TAC)	14.000 €	13.962 €	13.172 €	12.426 €	11.723 €	11.059 €

TCA	76.343 €

Location 4 – Public parking with NO direct street contact.

	2021	2022	2023	2024	2025	2026
Space adequacy	18.000 €					
Initial inversion	18.000 €					
To main infraestructures		6.800 €	6.800 €	6.800 €	6.800 €	6.800 €
To TEN-T roads		7.300 €	7.300 €	7.300 €	7.300 €	7.300 €
Added cost associated to distance		14.100 €	14.100 €	14.100 €	14.100 €	14.100 €
Leasing charge		1.300 €	1.300 €	1.300 €	1.300 €	1.300 €
Total Costs	18.000 €	15.400 €	15.400 €	15.400 €	15.400 €	15.400 €
Total Actualized Costs (TAC)	18.000 €	14.528 €	13.706 €	12.930 €	12.198 €	11.508 €

TCA	82.870 €

Location 5 – Public parking with NO direct street contact.

	2021	2022	2023	2024	2025	2026
Space adequacy	18.000 €					
Initial inversion	18.000 €					
To main infraestructures		7.300 €	7.300 €	7.300 €	7.300 €	7.300 €
To TEN-T roads		7.200 €	7.200 €	7.200 €	7.200 €	7.200 €
Added cost associated to distance		14.500 €	14.500 €	14.500 €	14.500 €	14.500 €
Leasing charge		1.300 €	1.300 €	1.300 €	1.300 €	1.300 €
Total Costs	18.000 €	15.800 €	15.800 €	15.800 €	15.800 €	15.800 €
Total Actualized Costs (TAC)	18.000 €	14.906 €	14.062 €	13.266 €	12.515 €	11.807 €

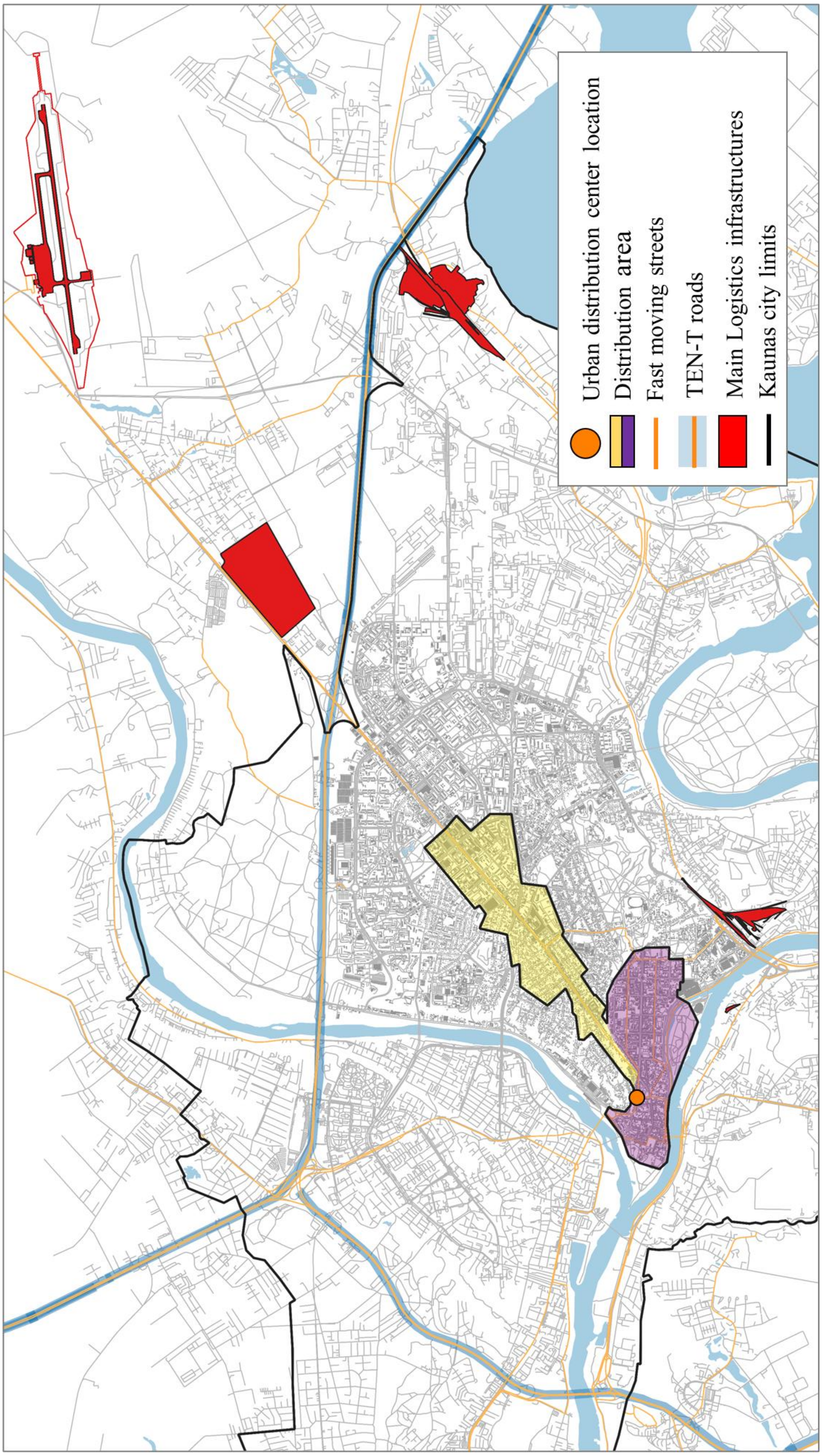
TCA	84.555 €

Location 7 – Public space in the street

	2021	2022	2023	2024	2025	2026
Space adequacy	10.000 €					
Initial inversion	10.000 €					
To main infraestructures		7.800 €	7.800 €	7.800 €	7.800 €	7.800 €
To TEN-T roads		7.300 €	7.300 €	7.300 €	7.300 €	7.300 €
Added cost associated to distance		15.100 €	15.100 €	15.100 €	15.100 €	15.100 €
Leasing charge		1.500 €	1.500 €	1.500 €	1.500 €	1.500 €
Total Costs	10.000 €	16.600 €	16.600 €	16.600 €	16.600 €	16.600 €
Total Actualized Costs (TAC)	10.000 €	15.660 €	14.774 €	13.938 €	13.149 €	12.404 €

TCA	79.925 €

5.2. Appendix 2. Urban Distribution Center Location



5.3. Appendix 3. Routes calculation: Clarke and Wright algorithm.

From 6 am to 7:30 am demand

1. Obtention of distance matrix through the open-source platform QGIS.

	0	1	2	3	4	5	6	7	8	9	10
0	0	351	395	365	1614	442	759	897	1117	1538	1664
1	351	0	401	696	1960	402	1056	1239	1424	1838	2000
2	395	401	0	719	1871	61	1126	1191	1466	1889	1957
3	365	696	719	0	1268	775	407	545	754	1177	1304
4	1614	1960	1871	1268	0	1931	1012	724	723	663	237
5	442	402	61	775	1931	0	1182	1252	1524	1947	2018
6	759	1056	1126	407	1012	1182	0	362	370	784	987
7	897	1239	1191	545	724	1252	362	0	378	752	770
8	1117	1424	1466	754	723	1524	370	378	0	423	646
9	1538	1838	1889	1177	663	1947	784	752	423	0	463
10	1664	2000	1957	1304	237	2018	987	770	646	463	0

2. Begin with an unfeasible solution in which every customer is supplied individually by a separate vehicle.

	O	D	O	D	
Q1	0	1	1	0	0,455
d1	0	351	0	351	701
Q2	0	2	2	0	0,273
d2		395		395	790
Q3	0	3	3	0	0,182
d3	0	365		365	731
Q4	0	4	4	0	0,091
d4		1614		1614	3228
Q5	0	5	5	0	0,476
d5		442		442	884
Q6	0	6	6	0	0,952
d6		759		759	1517
Q7	0	7	7	0	0,952
d7		897		897	1795
Q8	0	8	8	0	1,429
d8		1117		1117	2233
Q9	0	9	9	0	0,714
d9		1538		1538	3077
Q10	0	10	10	0	0,476
d10		1664		1664	3329

3. Combine any two of these single customer routes to use one less vehicle and reduce total distance. Later select the arc (*i*, *j*) with maximum saving subject to the requirement that the combined routes is feasible (does not exceed vehicle capacity).

Arc (1, 5) is selected.

		O	D	O	D	O	D	TOTAL	
Q1	Q2	0	1	1	2	2	0	0,727	Savings
d1	d2	0	351		401	0	395	1147	344
Q1	Q3	0	1	1	3	3	0	0,636	Savings
d1	d3	0	351		696	0	365	1412	20
Q1	Q4	0	1	1	4	4	0	0,545	Savings
d1	d4	0	351		1960	0	1614	3925	5
Q1	Q5	0	1	1	5	5	0	0,931	Savings
d1	d5	0	351		402	0	442	1195	391
Q1	Q6	0	1	1	6	6	0	1,407	Savings
d1	d6	0	351		1056	0	759	2165	53
Q1	Q7	0	1	1	7	7	0	1,407	Savings
d1	d7	0	351		1239	0	897	2487	9
Q1	Q8	0	1	1	8	8	0	1,883	X
d1	d8	0	351		1424	0	1117	2891	X
Q1	Q9	0	1	1	9	9	0	1,169	Savings
d1	d9	0	351		1838	0	1538	3727	50
Q1	Q10	0	1	1	10	10	0	0,931	Savings
d1	d10	0	351		2000	0	1664	4015	15

4. Repeat step 3 until the vehicle capacity is exceeded:

Arcs (1,5) and (5,10) are the ones that represent more savings.

			O	D	O	D	O	D	O	D		
Q1	Q5	Q2	0	1	1	5	5	2	2	0	1,203	Savings
d1	d5	d2	0	351		402		61	0	395	1208	776
Q1	Q5	Q3	0	1	1	5	5	3	3	0	1,113	Savings
d1	d5	d3	0	351		402		775	0	365	1893	32
Q1	Q5	Q4	0	1	1	5	5	4	4	0	1,022	Savings
d1	d5	d4	0	351		402		1931	0	1614	4298	125
Q1	Q5	Q6	0	1	1	5	5	6	6	0	1,883	X
d1	d5	d6	0	351		402		1182	0	759	2693	X
Q1	Q5	Q7	0	1	1	5	5	7	7	0	1,883	X
d1	d5	d7	0	351		402		1252	0	897	2902	X
Q1	Q5	Q9	0	1	1	5	5	9	9	0	1,645	X
d1	d5	d9	0	351		402		1947	0	1538	4238	X
Q1	Q5	Q10	0	1	1	5	5	10	10	0	1,407	Savings
d1	d5	d10	0	351		402		402	0	1664	2818	1705

Arcs (1,5), (5,10) and (10, 4) are the ones that represent more savings. As the capacity of the vehicle is exceeded, vehicles 1 route is closed.

				O	D	O	D	O	D	O	D	O	D		
Q1	Q5	Q10	Q2	0	1	1	5	5	10	10	2	2	0	1,680	X
d1	d5	d10	d2	0	351		402		402	0	1957	0	395	3156	X
Q1	Q5	Q10	Q3	0	1	1	5	5	10	10	3	3	0	1,589	X
d1	d5	d10	d3	0	351		402		402	0	1304	0	365	2473	X
Q1	Q5	Q10	Q4	0	1	1	5	5	10	10	4	4	0	1,50	Savings
d1	d5	d10	d4	0	351		402		402	0	237	0	1614	3005	1927

5. Begin again with an unfeasible solution in which every customer is supplied individually by a separate vehicle. The points that have all their capacity served are not used anymore.

Arc (2, 9) is selected.

		O	D	O	D	O	D		
Q2	Q3	0	2	2	3	3	0	0,455	Savings
d2	d3		395		719		365	1479	41
Q2	Q6	0	2	2	6	6	0	1,225	Savings
d2	d6		395		1126		759	2280	27
Q2	Q7	0	2	2	7	7	0	1,225	Savings
d2	d7		395		1191		897	2484	101
Q2	Q8	0	2	2	8	8	0	1,701	X
d2	d8		0		1466		1117	1466	X
Q2	Q9	0	2	2	9	9	0	0,987	Savings
d2	d9		395		1889		1538	3823	296

6. Repeat step 3 until the vehicle capacity is exceeded:

Arcs (2, 9) and (9, 3) are the ones that represent more savings.

			O	D	O	D	O	D	O	D		
Q2	Q9	Q3	0	2	2	9	9	3	3	0	1,169	Savings
d2	d9	d3		395		1889		1177			3461	1092
Q2	Q9	Q6	0	2	2	9	9	6	6	0	1,939	X
d2	d9	d6		395		1889		784			3068	X
Q2	Q9	Q7	0	2	2	9	9	7	7	0	1,939	X
d2	d9	d7		395		1889		752			3461	X

Arcs (2, 9), (9, 3) and (3, 8) are the ones that represent more savings. To point 8 it is only served 0,331 m^3. As the capacity of the vehicle is exceeded, vehicles 1 route is closed.

				O	D	O	D	O	D	O	D	O	D		
Q2	Q9	Q3	Q6	0	2	2	9	9	3	3	6	6	0	1,169	Savings
d2	d9	d3	d6		395		1889		1177		407		759	4627	351
Q2	Q9	Q3	Q7	0	2	2	9	9	3	3	7	7	0	1,169	Savings
d2	d9	d3	d7		395		1889		1177		545		897	4904	353
Q2	Q9	Q3	Q8	0	2	2	9	9	3	3	8	8	0	1,50	Savings
d2	d9	d3	d8		395		1889		1177		754		1117	5332	362
														0,331	Capacity

7. Begin again with an unfeasible solution in which every customer is supplied individually by a separate vehicle. The points that have all their capacity served are not used anymore.

Then route of vehicle 3 is made of arc (7, 8) and route of vehicle 4 is made of arc (6, 8).

		O	D	O	D	O	D		
Q8	Q7	0	8	8	7	7	0	0,952	Savings
d8	d7		1117		378		897	2392	1637
Q8	Q6	0	8	8	6	6	0	2,381	Savings
d8	d6		1117		370		759	2245	1506

		O	D	O	D	O	D		
Q6	Q7	0	6	6	7	7	0	1,905	Savings
d6	d7		759		362		897	2018	1294
Q6	Q8	0	6	6	8	8	0	2,050	Savings
d6	d8		759		370		1117	2245	1506

From 7:30 am to 10:30 am demand

1. Obtention of distance matrix through the open-source platform QGIS.

	0	5	6	7	8	9	10	11	12	13	14	15
0	0	442	759	897	1117	1538	1664	664	459	869	1299	1411
5	442	0	1182	1252	1524	1947	2018	271	785	1299	1658	1844
6	759	1182	0	362	370	784	987	1421	485	129	641	666
7	897	1252	362	0	378	752	770	1516	467	429	406	789
8	1117	1524	370	378	0	423	646	1774	767	306	351	412
9	1538	1947	784	752	423	0	463	2197	1184	693	459	323
10	1664	2018	987	770	646	463	0	2284	1235	949	365	773
11	664	271	1421	1516	1774	2197	2284	0	1049	1532	1922	2075
12	459	785	485	467	767	1184	1235	1049	0	614	873	1136
13	869	1299	129	429	306	693	949	1532	614	0	626	545
14	1299	1658	641	406	351	459	365	1922	873	626	0	653
15	1411	1844	666	789	412	323	773	2075	1136	545	653	0

2. Begin with an unfeasible solution in which every customer is supplied individually by a separate vehicle.

	O	D	O	D	
Q5	0	1	1	0	0,476
d5	0	442	0	442	884
Q6	0	2	2	0	0,952
d6		759		759	1517
Q7	0	3	3	0	0,952
d7	0	897		897	1795
Q8	0	4	4	0	1,429
d8		1117		1117	2233
Q9	0	5	5	0	0,714
d9		1538		1538	3077
Q10	0	6	6	0	0,476
d10		1664		1664	3329
Q11	0	7	7	0	0,143
d11		664		664	1328
Q12	0	8	8	0	0,190
d12		459		459	918
Q13	0	9	9	0	0,238
d13		869		869	1737
Q14	0	10	10	0	0,143
d14		1299		1299	2598
Q15	0	11	11	0	0,286
d15		1411		1411	2823

3. Combine any two of these single customer routes to use one less vehicle and reduce total distance. Later select the arc (i, j) with maximum saving subject to the requirement that the combined routes is feasible (does not exceed vehicle capacity).

Arc (5, 11) is the one that represent more savings.

		O	D	O	D	O	D		
Q5	Q6	0	1	1	2	2	0	1,429	Ahorro
d5	d6	0	442		1182	0	759	2383	19
Q5	Q7	0	1	1	3	3	0	1,429	Ahorro
d5	d7	0	442		1252	0	897	2591	88
Q5	Q8	0	1	1	4	4	0	1,905	x
d5	d8	0	442		1524	0	1117	3083	x
Q5	Q9	0	1	1	5	5	0	1,190	Ahorro
d5	d9	0	442		1947	0	1538	3928	33
Q5	Q10	0	1	1	6	6	0	0,952	Ahorro
d5	d10	0	442		2018	0	1664	4124	89
Q5	Q11	0	1	1	7	7	0	0,619	Ahorro
d5	d11	0	442		271	0	664	1377	835
Q5	Q12	0	1	1	8	8	0	0,667	Ahorro
d5	d12	0	442		785	0	459	1686	116
Q5	Q13	0	1	1	9	9	0	0,714	Ahorro
d5	d13	0	442		1299	0	869	2610	12
Q5	Q14	0	1	1	10	10	0	0,619	Ahorro
d5	d14	0	442		1658	0	1299	3399	84
Q5	Q15	0	1	1	11	11	0	0,762	Ahorro
d5	d15	0	442		1844	0	1411	3698	10

4. Repeat step 3 until the vehicle capacity is exceeded:

Arcs (5, 11) and (11, 12) are the ones that represent more savings.

			O	D	O	D	O	D	O	D		
Q5	Q11	Q6	0	1	1	7	7	2	2	0	1,57	Ahorro
d5	d11	d6	0	442		271		1421	0	759	2893	1
Q5	Q11	Q7	0	1	1	7	7	3	3	0	1,57	Ahorro
d5	d11	d7	0	442		271		1516	0	897	3126	45
Q5	Q11	Q9	0	1	1	7	7	5	5	0	1,33	Ahorro
d5	d11	d9	0	442		271		2197	0	1538	4448	5
Q5	Q11	Q10	0	1	1	7	7	6	6	0	1,10	Ahorro
d5	d11	d10	0	442		271		2284	0	1664	4661	44
Q5	Q11	Q12	0	1	1	7	7	8	8	0	0,81	Ahorro
d5	d11	d12	0	442		271		1049	0	459	2221	73
Q5	Q11	Q13	0	1	1	7	7	9	9	0	0,86	Ahorro
d5	d11	d13	0	442		271		1532	0	869	3114	0
Q5	Q11	Q14	0	1	1	7	7	10	10	0	0,76	Ahorro
d5	d11	d14	0	442		271		1922	0	1299	3934	40
Q5	Q11	Q15	0	1	1	7	7	11	11	0	0,90	Ahorro
d5	d11	d15	0	442		271		2075	0	1411	4199	1

Arcs (5, 11), (11, 12) and (12, 10) are the ones that represent more savings.

				O	D	O	D	O	D	O	D	O	D		
Q5	Q11	Q12	Q6	0	1	1	7	7	8	8	2	2	0	1,762	Ahorro
d5	d11	d12	d6	0	442		271		1049	0	485	0	759	3006	732
Q5	Q11	Q12	Q7	0	1	1	7	7	8	8	3	3	0	1,762	x
d5	d11	d12	d7	0	442		271		402	0	467	0	897,47386	2479	x
Q5	Q11	Q12	Q9	0	1	1	7	7	8	8	5	5	0	1,52	Ahorro
d5	d11	d12	d9	0	442		271		402	0	1184	0	1538,3429	3837	1461
Q5	Q11	Q12	Q10	0	1	1	7	7	8	8	6	6	0	1,29	Ahorro
d5	d11	d12	d10	0	442		271		402	0	1235	0	1664,2724	4014	1536
Q5	Q11	Q12	Q13	0	1	1	7	7	8	8	9	9	0	1,05	Ahorro
d5	d11	d12	d13	0	442		271		402	0	614	0	868,58911	2597	1361
Q5	Q11	Q12	Q14	0	1	1	7	7	8	8	10	10	0	0,95	Ahorro
d5	d11	d12	d14	0	442		271		402	0	873	0	1298,9182	3287	1532
Q5	Q11	Q12	Q15	0	1	1	7	7	8	8	11	11	0	1,10	Ahorro
d5	d11	d12	d15	0	442		271		402	0	1136	0	1411,3582	3662	1382

Arcs (5, 11), (11, 12), (12, 10) and (10, 14) are the ones that represent more savings. As the capacity of the vehicle is exceeded, vehicles 1 route is closed.

					O	D	O	D	O	D	O	D	O	D	O	D		
Q5	Q11	Q12	Q10	Q6	0	1	1	7	7	8	8	6	6	2	2	0	2,238	Ahorro
d5	d11	d12	d10	d6	0	442		271		1049	0	1235	0	987	0	759	4743	788
Q5	Q11	Q12	Q10	Q7	0	1	1	7	7	8	8	6	6	3	3	0	2,238	Ahorro
d5	d11	d12	d10	d7	0	442		271		402	0	1235	0	770	0	897	4017	1792
Q5	Q11	Q12	Q10	Q9	0	1	1	7	7	8	8	6	6	5	5	0	2,00	Ahorro
d5	d11	d12	d10	d9	0	442		271		402	0	1235	0	463	0	1538	4351	2739
Q5	Q11	Q12	Q10	Q13	0	1	1	7	7	8	8	6	6	9	9	0	1,52	Ahorro
d5	d11	d12	d10	d13	0	442		271		402	0	1235	0	949	0	869	4167	1584
Q5	Q11	Q12	Q10	Q14	0	1	1	7	7	8	8	6	6	10	10	0	1,43	Ahorro
d5	d11	d12	d10	d14	0	442		271		402	0	1235	0	365	0	1299	4014	2598
Q5	Q11	Q12	Q10	Q15	0	1	1	7	7	8	8	6	6	11	11	0	1,57	Ahorro
d5	d11	d12	d10	d15	0	442		271		402	0	1235	0	773	0	1411	4534	2302

5. Begin again with an unfeasible solution in which every customer is supplied individually by a separate vehicle. The points that have all their capacity served are not used anymore.

Arc (6, 13) is the one that represent more savings.

		O	D	O	D	O	D		
Q6	Q7	0	2	2	3	3	0	1,905	Ahorro
d6	d7		759		362		897	2018	1294
Q6	Q8	0	2	2	4	4	0	2,381	Ahorro
d6	d8		759		370		1117	2245	1506
Q6	Q9	0	2	2	5	5	0	1,667	Ahorro
d6	d9		759		784		1538	3081	1513
Q6	Q13	0	2	2	9	9	0	1,190	Ahorro
d6	d13		759		129		869	887	2367
Q6	Q15	0	2	2	11	11	0	1,238	Ahorro
d6	d15		759		666		1411	2836	1504

Arcs (6, 13) and (13, 15) are the ones that represent more savings. As the capacity of the vehicle is exceeded, vehicles 2 route is closed.

			O	D	O	D	O	D	O	D		
Q6	Q13	Q7	0	2	2	9	9	3	3	0	2,143	x
d6	d13	d7		759		129		429		759	2075	x
Q6	Q13	Q8	0	2	2	9	9	4	4	0	2,619	x
d6	d13	d8		759		129		306		759	1952	x
Q6	Q13	Q9	0	2	2	9	9	5	5	0	1,905	x
d6	d13	d9		759		129		693		759	3461	x
Q6	Q13	Q15	0	2	2	9	9	11	11	0	1,476	Ahorro
d6	d13	d15		759		129		545		759	3461	249

7. Begin again with an unfeasible solution in which every customer is supplied individually by a separate vehicle. The points that have all their capacity served are not used anymore.

Then route of vehicle 3 is made of arc (7, 9) and route of vehicle 4 is made of arc (8, 9).

		O	D	O	D	O	D		
Q7	Q8	0	3	3	4	4	0	2,381	Ahorro
d7	d8		897		378		1117	2392	1637
Q7	Q9	0	3	3	5	5	0	1,595	Ahorro
d7	d9		897		752		1538	3188	1684

		O	D	O	D	O	D		
Q8	Q9	0	4	4	5	5	0	2,143	Ahorro
d8	d9		1117		423		1538	3078	2232

From 10:30 am to 4:30 pm demand

1. Obtention of distance matrix through the open-source platform QGIS.

	0	1	2	3	4	11	12	13	14	15
0	0	351	395	365	1614	664	459	869	1299	1411
1	351	0	401	696	1960	473	809	1150	1635	1674
2	395	401	0	719	1871	331	724	1244	1597	1790
3	365	696	719	0	1268	1020	208	528	939	1073
4	1614	1960	1871	1268	0	2201	1164	1003	377	947
11	664	473	331	1020	2201	0	1049	1532	1922	2075
12	459	809	724	208	1164	1049	0	614	873	1136
13	869	1150	1244	528	1003	1532	614	0	626	545
14	1299	1635	1597	939	377	1922	873	626	0	653
15	1411	1674	1790	1073	947	2075	1136	545	653	0

2. Begin with an unfeasible solution in which every customer is supplied individually by a separate vehicle.

	O	D	O	D	
Q1	0	1	1	0	1,250
d1	0	351	0	351	701
Q2	0	2	2	0	0,750
d2		395		395	790
Q3	0	3	3	0	0,500
d3	0	365		365	731
Q4	0	4	4	0	0,250
d4		1614		1614	3228
Q11	0	5	5	0	0,464
d11		664		664	1328
Q12	0	6	6	0	0,619
d12		459		459	918
Q13	0	7	7	0	0,774
d13		869		869	1737
Q14	0	8	8	0	0,464
d14		1299		1299	2598
Q15	0	9	9	0	0,929
d15		1411		1411	2823

3. Combine any two of these single customer routes to use one less vehicle and reduce total distance. Later select the arc (*i*, *j*) with maximum saving subject to the requirement that the combined routes is feasible (does not exceed vehicle capacity).

Arc (1, 11) is the one that represent more savings. As the capacity of the vehicle is exceeded, vehicles 1 route is closed. Point 11 will be served by another vehicle.

		O	D	O	D	O	D		
Q1	Q2	0	1	1	2	2	0	2,000	Ahorro
d1	d2	0	351		401	0	395	1147	344
Q1	Q3	0	1	1	3	3	0	1,750	Ahorro
d1	d3	0	351		696	0	365	1412	20
Q1	Q4	0	1	1	4	4	0	1,500	Ahorro
d1	d4	0	351		1960	0	1614	3925	5
Q1	Q11	0	1	1	5	5	0	1,714	Ahorro
d1	d11	0	351		473	0	664	1487	541
Q1	Q12	0	1	1	6	6	0	1,869	Ahorro
d1	d12	0	351		809	0	459	1619	0
Q1	Q13	0	1	1	7	7	0	2,024	Ahorro
d1	d13	0	351		1150	0	869	2369	70
Q1	Q14	0	1	1	8	8	0	1,714	Ahorro
d1	d14	0	351		1635	0	1299	3285	14
Q1	Q15	0	1	1	9	9	0	2,179	Ahorro
d1	d15	0	351		1674	0	1411	3436	88

4. Repeat step 3 until the vehicle capacity is exceeded:

Arc (2, 11) is the one that represent more savings.

		O	D	O	D	O	D		
Q2	Q3	0	2	2	3	3	0	1,250	Ahorro
d2	d3	0	395		719	0	365	1479	41
Q2	Q4	0	2	2	4	4	0	1,000	Ahorro
d2	d4	0	395		1871	0	1614	3880	138
Q2	Q11	0	2	2	5	5	0	0,964	Ahorro
d2	d11	0	395		331	0	664	1390	728
Q2	Q12	0	2	2	6	6	0	1,369	Ahorro
d2	d12	0	395		724	0	459	1578	129
Q2	Q13	0	2	2	7	7	0	1,524	Ahorro
d2	d13	0	395		1244	0	869	2508	19
Q2	Q14	0	2	2	8	8	0	1,214	Ahorro
d2	d14	0	395		1597	0	1299	3291	97
Q2	Q15	0	2	2	9	9	0	1,679	Ahorro
d2	d15	0	395		1790	0	1411	3596	17

Arcs (6, 11) and (11, 4) are the ones that represent more savings.

			O	D	O	D	O	D	O	D		
Q2	Q11	Q3	0	2	2	5	5	3	3	0	1,714	Ahorro
d2	d11	d3	0	395		331		1020	0	365	2111	9
Q2	Q11	Q4	0	2	2	5	5	4	4	0	1,214	Ahorro
d2	d11	d4	0	395		331		2201	0	1614	4541	77
Q2	Q11	Q12	0	2	2	5	5	6	6	0	1,833	Ahorro
d2	d11	d12	0	395		331		1049	0	459	2234	73
Q2	Q11	Q13	0	2	2	5	5	7	7	0	1,988	Ahorro
d2	d11	d13	0	395		331		1532	0	869	3127	0
Q2	Q11	Q14	0	2	2	5	5	8	8	0	1,679	Ahorro
d2	d11	d14	0	395		331		1922	0	1299	3947	40
Q2	Q11	Q15	0	2	2	5	5	9	9	0	2,143	Ahorro
d2	d11	d15	0	395		331		2075	0	1411	4212	1

Arcs (6, 11), (11, 4) and (4, 15) are the ones that represent more savings. As the capacity of the vehicle is exceeded, vehicles 2 route is closed.

				O	D	O	D	O	D	O	D	O	D		
Q2	Q11	Q4	Q3	0	2	2	5	5	4	4	3	3	0	1,964	Ahorro
d2	d11	d4	d3	0	395		331		2201	0	1268	0	365	4561	711
Q2	Q11	Q4	Q12	0	2	2	5	5	4	4	6	6	0	2,083	Ahorro
d2	d11	d4	d12	0	395		331		2201	0	1164	0	459	4550	909
Q2	Q11	Q4	Q13	0	2	2	5	5	4	4	7	7	0	2,238	Ahorro
d2	d11	d4	d13	0	395		331		2201	0	1003	0	869	4799	1479
Q2	Q11	Q4	Q14	0	2	2	5	5	4	4	8	8	0	1,500	Ahorro
d2	d11	d4	d14	0	395		331		2201	0	377	0	1299	4603	2536
Q2	Q11	Q4	Q15	0	2	2	5	5	4	4	9	9	0	2,39	Ahorro
d2	d11	d4	d15	0	395		331		2201	0	947	0	1411,358	5286	2078

7. Begin again with an unfeasible solution in which every customer is supplied individually by a separate vehicle. The points that have all their capacity served are not used anymore.

Arc (3, 14) is the one that represent more savings.

		O	D	O	D	O	D		
Q3	Q12	0	3	3	6	6	0	1,119	Ahorro
d3	d12		365		208		459	1032	617
Q3	Q13	0	3	3	7	7	0	1,274	Ahorro
d3	d13		365		528		869	1762	706
Q3	Q14	0	3	3	8	8	0	0,678	Ahorro
d3	d14		0		939		1299	939	2389
Q3	Q15	0	3	3	9	9	0	1,429	Ahorro
d3	d15		365		1073		1411	2849	704

Arcs (3, 8) and (8, 13) are the ones that represent more savings. As the capacity of the vehicle is exceeded, vehicles 3 route is closed.

			O	D	O	D	O	D	O	D		
Q3	Q8	Q12	0	3	3	8	8	6	6	0	1,583	Ahorro
d3	d8	d12		365		939		873			2177	-321
Q3	Q8	Q13	0	3	3	8	8	7	7	0	1,452	Ahorro
d3	d8	d13		365		939		626			1931	745
Q3	Q8	Q15	0	3	3	8	8	9	9	0	1,893	Ahorro
d3	d8	d15		365		939		653			3461	300

Then route of vehicle 4 is made of arc (12, 15).

		O	D	O	D	O	D		
Q12	Q15	0	6	6	9	9	0	1,548	Ahorro
d12	d15		459		1136		1411	3006	735

From 4:30 pm to 9 pm demand

1. Obtention of distance matrix through the open-source platform QGIS.

	0	1	2	3	4	5	6	7	8
0	0	351	395	365	1614	870	211	1712	1428
1	351	0	401	696	1960	1114	417	2035	1692
2	395	401	0	719	1871	1260	230	2031	1806
3	365	696	719	0	1268	569	492	1347	1089
4	1614	1960	1871	1268	0	1153	1656	442	945
5	870	1114	1260	569	1153	0	1044	1037	580
6	211	417	230	492	1656	1044	0	1804	1581
7	1712	2035	2031	1347	442	1037	1804	0	628
8	1428	1692	1806	1089	945	580	1581	628	0

2. Begin with an unfeasible solution in which every customer is supplied individually by a separate vehicle.

	O	D	O	D	
Q1	0	1	1	0	0,455
d1	0	351	0	351	701
Q2	0	2	2	0	0,273
d2		395		395	790
Q3	0	3	3	0	0,182
d3	0	365		365	731
Q4	0	4	4	0	0,091
d4		1614		1614	3228
Q5	0	5	5	0	1,333
d5		870		870	1741
Q6	0	6	6	0	1,333
d6		211		211	423
Q7	0	7	7	0	1,000
d7		1712		1712	3423
Q8	0	8	8	0	1,333
d8		1428		1428	2857

3. Combine any two of these single customer routes to use one less vehicle and reduce total distance. Later select the arc (i, j) with maximum saving subject to the requirement that the combined routes is feasible (does not exceed vehicle capacity).

Arc (1, 2) is the one that represent more savings.

		O	D	O	D	O	D		
Q1	Q2	0	1	1	2	2	0	0,727	Ahorro
d1	d2	0	351		401	0	395	1147	344
Q1	Q3	0	1	1	3	3	0	0,636	Ahorro
d1	d3	0	351		696	0	365	1412	20
Q1	Q4	0	1	1	4	4	0	0,545	Ahorro
d1	d4	0	351		1960	0	1614	3925	5
Q1	Q5	0	1	1	5	5	0	1,788	Ahorro
d1	d5	0	351		1114	0	870	2335	107
Q1	Q6	0	1	1	6	6	0	1,788	Ahorro
d1	d6	0	351		417	0	211	979	145
Q1	Q7	0	1	1	7	7	0	1,455	Ahorro
d1	d7	0	351		2035	0	1712	4097	28
Q1	Q8	0	1	1	8	8	0	1,788	Ahorro
d1	d8	0	351		1692	0	1428	3471	87

4. Repeat step 3 until the vehicle capacity is exceeded:

Arcs (1, 2) and (2, 4) are the ones that represent more savings.

			O	D	O	D	O	D	O	D		
Q1	Q2	Q3	0	1	1	2	2	3	3	0	0,909	Ahorro
d1	d2	d3	0	351		401		719	0	365	1836	41
Q1	Q2	Q4	0	1	1	2	2	4	4	0	0,818	Ahorro
d1	d2	d4	0	351		401		1871	0	1614	4237	138
Q1	Q2	Q5	0	1	1	2	2	5	5	0	2,061	Ahorro
d1	d2	d5	0	351		401		1260	0	870	2882	5
Q1	Q2	Q6	0	1	1	2	2	6	6	0	2,061	Ahorro
d1	d2	d6	0	351		401		230	0	211	1193	377
Q1	Q2	Q7	0	1	1	2	2	7	7	0	1,727	Ahorro
d1	d2	d7	0	351		401		2031	0	1712	4495	75
Q1	Q2	Q8	0	1	1	2	2	8	8	0	2,061	Ahorro
d1	d2	d8	0	351		401		1806	0	1428	3986	17

Arcs (1, 2), (2, 4) and (4, 3) are the ones that represent more savings.

				O	D	O	D	O	D	O	D	O	D		
Q1	Q2	Q4	Q3	0	1	1	2	2	4	4	3	3	0	1,000	Ahorro
d1	d2	d4	d3	0	351		401		1871	0	1268	0	365	4256	711
Q1	Q2	Q4	Q5	0	1	1	2	2	4	4	5	5	0	2,152	Ahorro
d1	d2	d4	d5	0	351		401		1871	0	1153	0	870	4646	1332
Q1	Q2	Q4	Q6	0	1	1	2	2	4	4	6	6	0	2,152	Ahorro
d1	d2	d4	d6	0	351		401		1871	0	1656	0	211	4490	170
Q1	Q2	Q4	Q7	0	1	1	2	2	4	4	7	7	0	1,818	Ahorro
d1	d2	d4	d7	0	351		401		1871	0	442	0	1712	4776	2884
Q1	Q2	Q4	Q8	0	1	1	2	2	4	4	8	8	0	2,15	Ahorro
d1	d2	d4	d8	0	351		401		1871	0	945	0	1428,3446	4996	2097

Arcs (1, 2), (2, 4), (4, 3) and (3, 7) are the ones that represent more savings. As the capacity of the vehicle is exceeded, vehicles 1 route is closed.

					O	D	O	D	O	D	O	D	O	D	O	D		
Q1	Q2	Q4	Q3	Q5	0	1	1	2	2	4	4	3	3	5	5	0	2,333	Ahorro
d1	d2	d4	d3	d5	0	351		401		1871	0	1268	0	569	0	870	5331	666
Q1	Q2	Q4	Q3	Q6	0	1	1	2	2	4	4	3	3	6	6	0	2,333	Ahorro
d1	d2	d4	d3	d6	0	351		401		1871	0	1268	0	492	0	211	4594	85
Q1	Q2	Q4	Q3	Q7	0	1	1	2	2	4	4	3	3	7	7	0	1,500	Ahorro
d1	d2	d4	d3	d7	0	351		401		1871	0	1268	0	1347	0	1712	6949	730
Q1	Q2	Q4	Q3	Q8	0	1	1	2	2	4	4	3	3	8	8	0	2,333	Ahorro
d1	d2	d4	d3	d8	0	351		401		1871	0	1268	0	1089	0	1428	6408	705

5. Begin again with an unfeasible solution in which every customer is supplied individually by a separate vehicle. The points that have all their capacity served are not used anymore.

Arc (5, 8) is the one that represent more savings. As the capacity of the vehicle is exceeded, vehicles 2 route is closed.

		O	D	O	D	O	D		
Q5	Q6	0	5	5	6	6	0	2,667	Ahorro
d5	d6		870		1044		211	2126	38
Q5	Q7	0	5	5	7	7	0	1,500	Ahorro
d5	d7		870		1037		1712	3619	1546
Q5	Q8	0	5	5	8	8	0	1,500	Ahorro
d5	d8		870		580		1428	1450	3147

Arc (6, 7) is the one that represent more savings. As the capacity of the vehicle is exceeded, vehicles 3 route is closed.

		O	D	O	D	O	D		
Q6	Q7	0	6	6	7	7	0	1,500	Ahorro
d6	d7		211		1804		1712	3727	3846
Q6	Q8	0	6	6	8	8	0	2,500	Ahorro
d6	d8		211		1581		1428	3221	59

Then route of vehicle 4 is made of arc (7, 8).

		O	D	O	D	O	D		
Q7	Q8	0	7	7	8	8	0	1,500	Ahorro
d7	d8		1712		628		1428	3768	2512

5.4. Appendix 4. Demand simplification problem

1. All closest locations have been grouped in different points that will represent them.

Locations	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Points	1					2			3		4

Locations	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
Points	5		6				7			

Locations	B11	B12	B13	B14	B15	B16	B17	B18	B19	B20	B21
Points	8						9			10	

Locations	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Points	11			12				13				

Locations	C13	C14	C15	C16	C17	C18	C19	C20	C21
Points	14			15					

Locations	D1	D2	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15	D16
Points	16				17					18		19			

2. Demand is distributed uniformly for all locations and so each point contains the sum of demands of the locations that represent.

Points	1	2	3	4
Demand	0,45	0,27	0,18	0,09

Points	5	6	7	8	9	10
Demand	0,48	0,95	0,95	1,43	0,71	0,48

Points	11	12	13	14	15
Demand	0,14	0,19	0,24	0,14	0,29

Points	16	17	18	19
Demand	1,33	1,33	1	1,33

3. See the map with the new points.

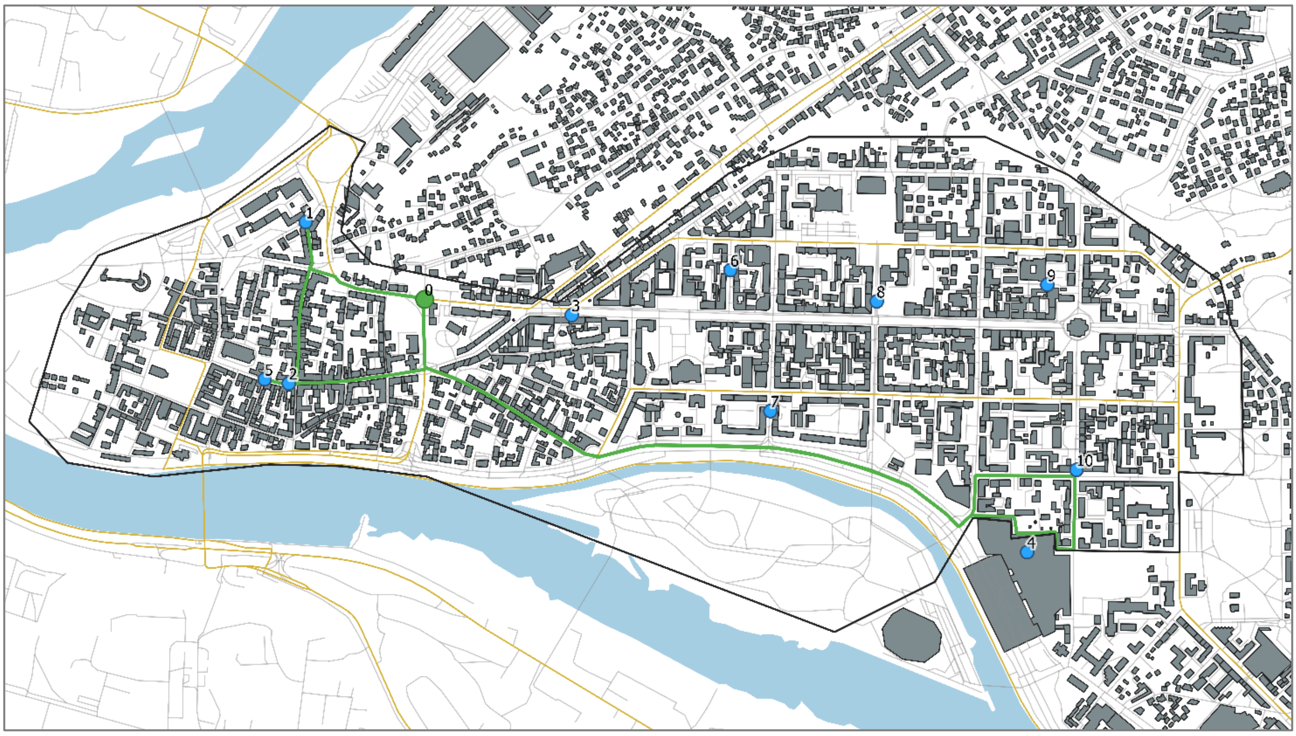
- Yellow points for group A.
- Blue points for group B.
- Red points for group C.
- Orange points for group D.


18
10
9
4
15
19
14
8
13
16
7
6
3
12
0
17
1
2
5
11

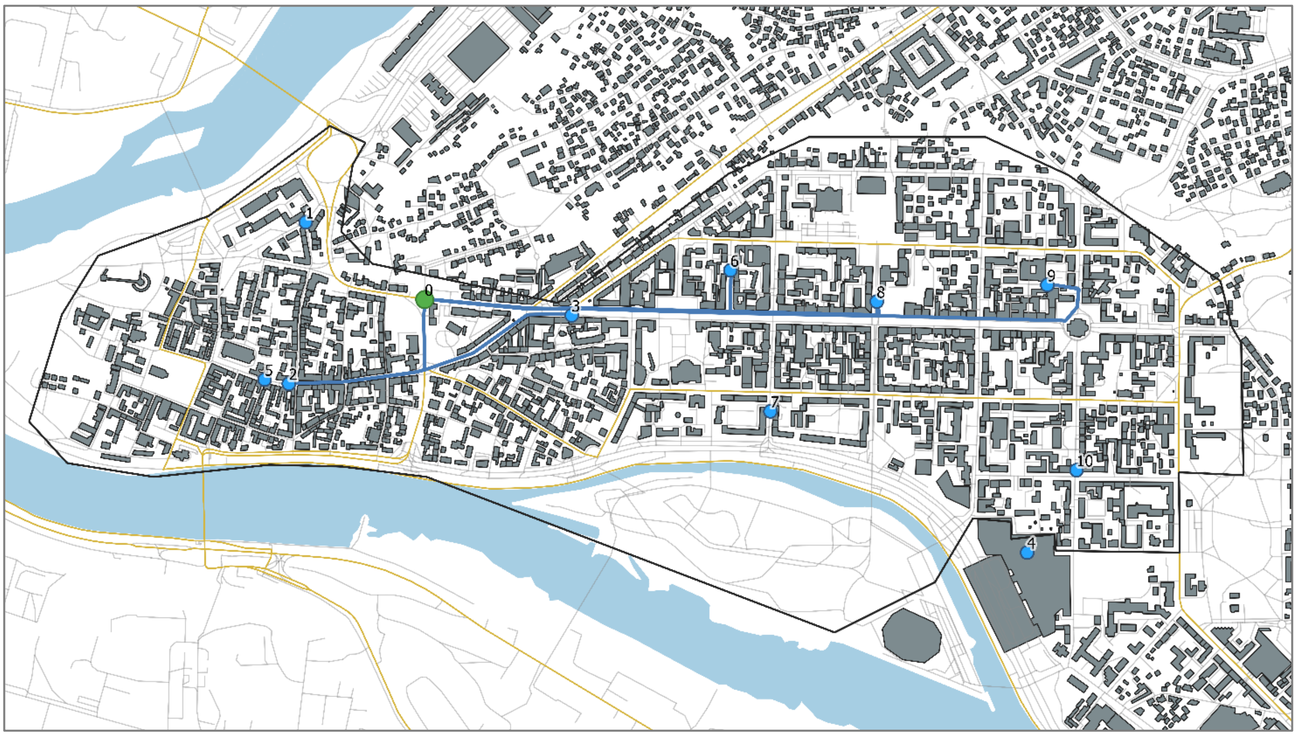
5.5. Appendix 5. Routes map representation.

Routes from 6 am to 7:30 am

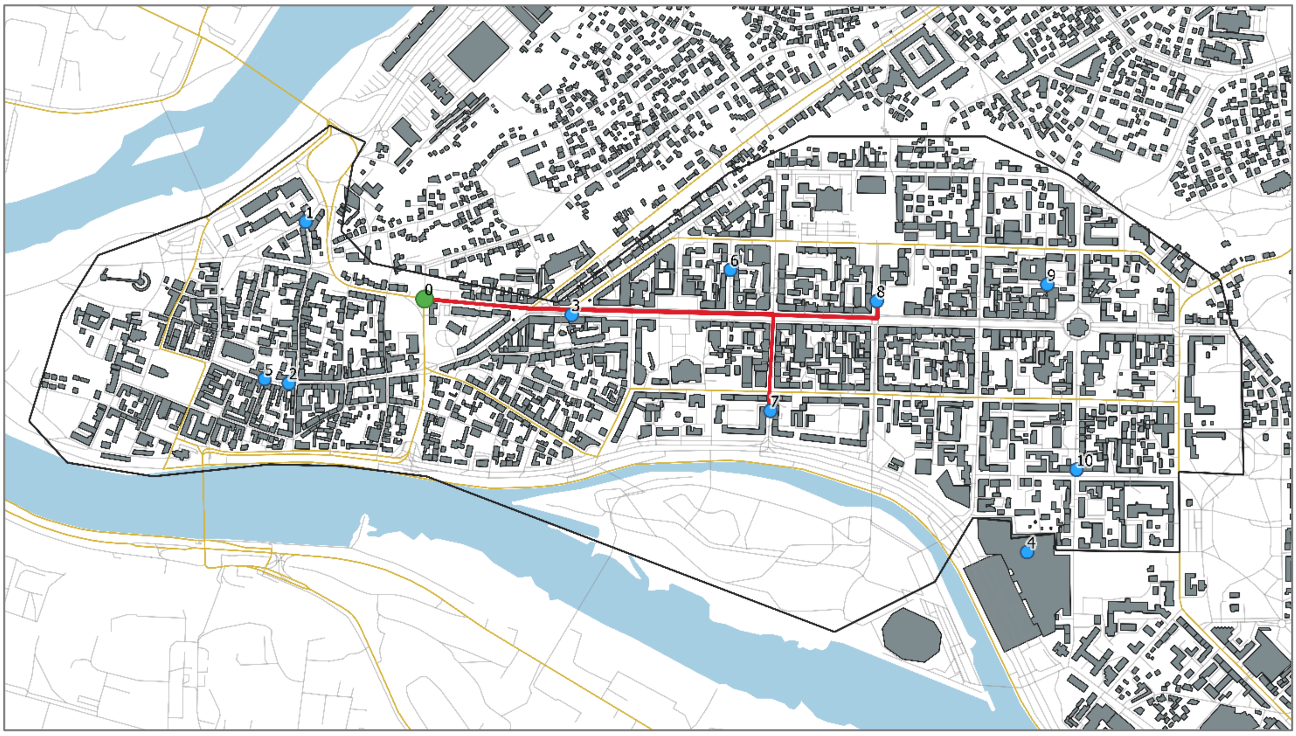
- Vehicle 1



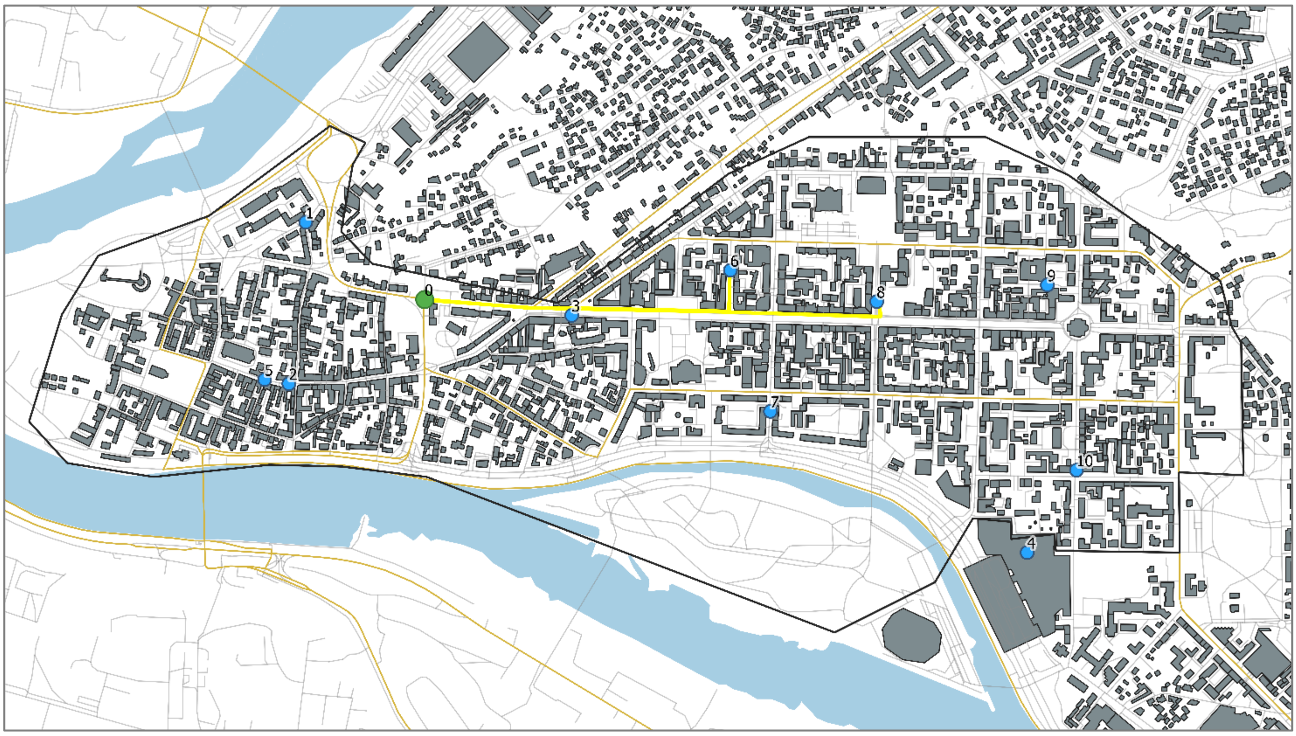
- Vehicle 2



- Vehicle 3

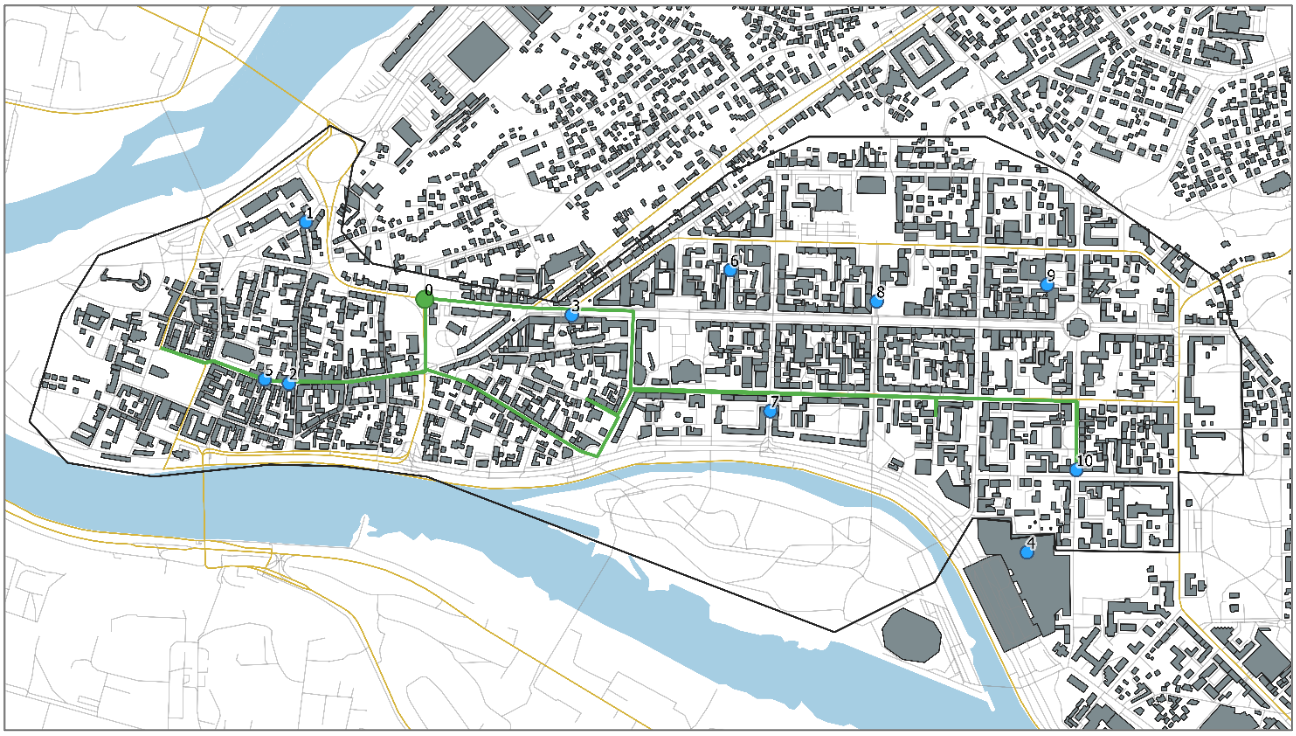


- Vehicle 4

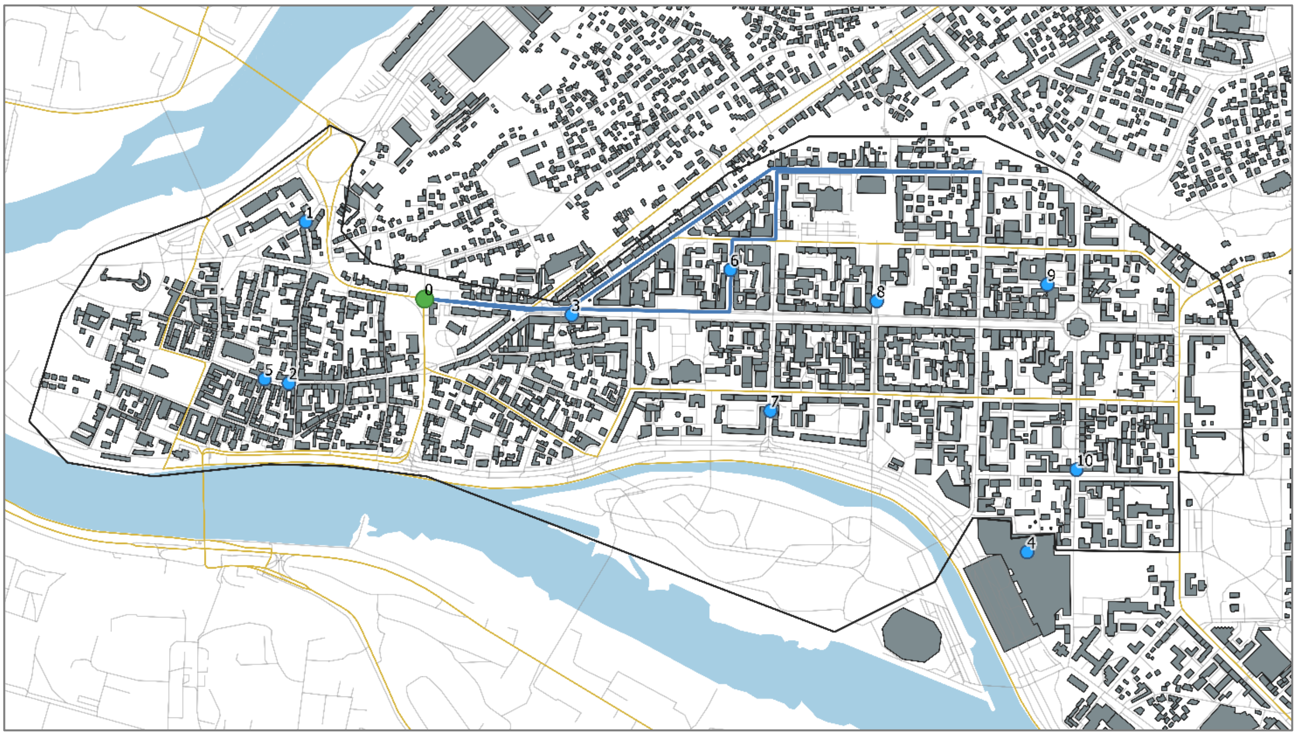


Routes from 7:30 am to 10:30 am

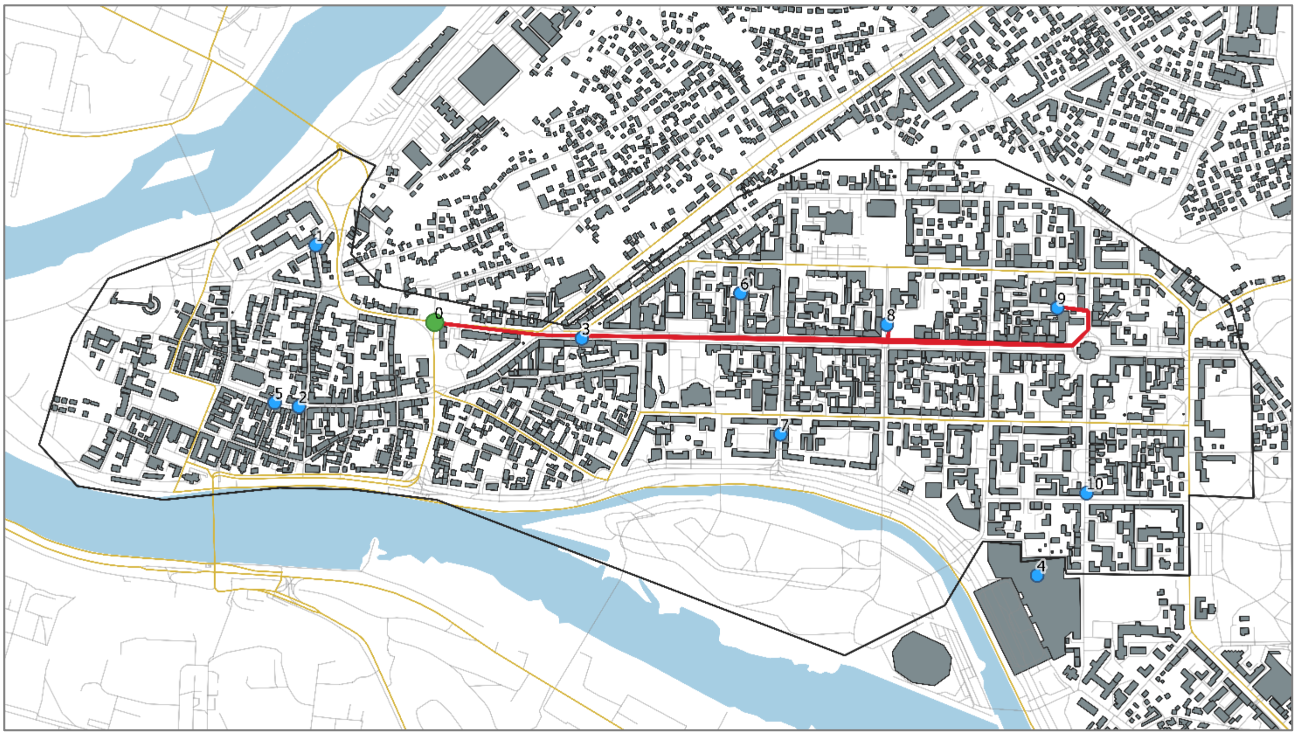
- Vehicle 1



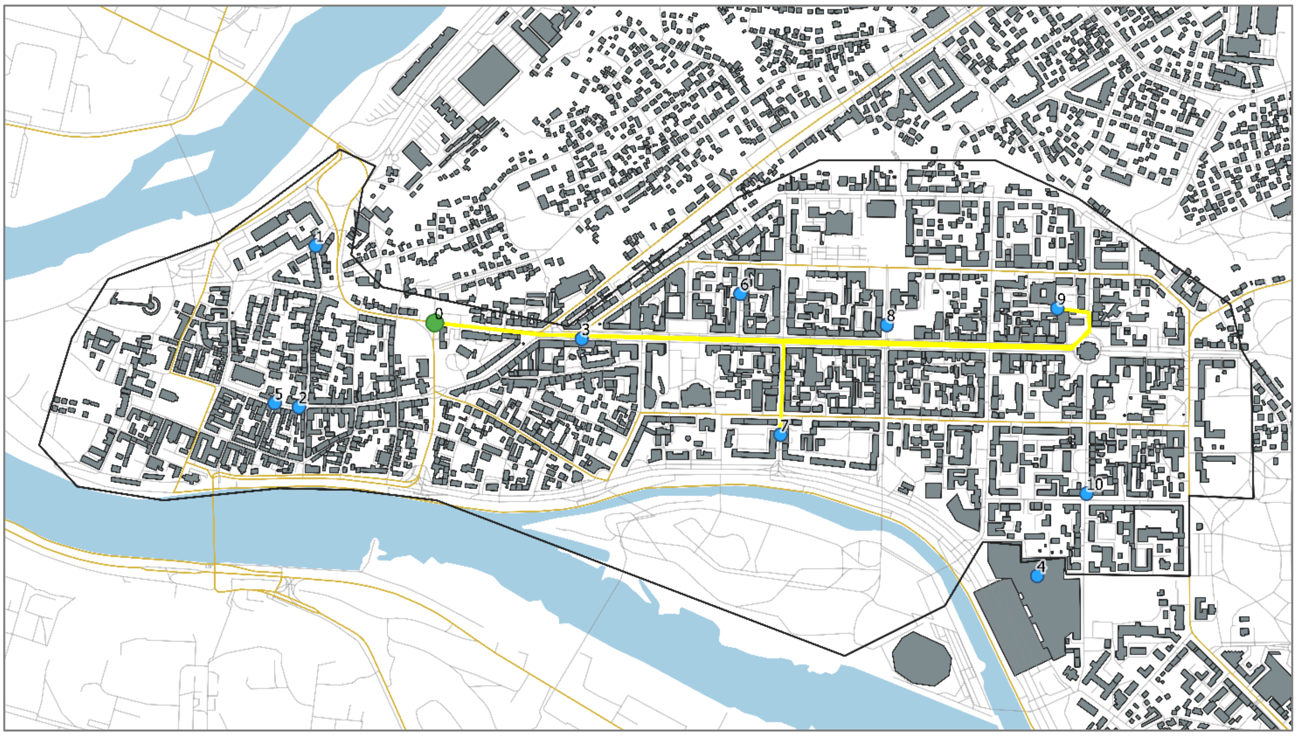
- Vehicle 2



- Vehicle 3

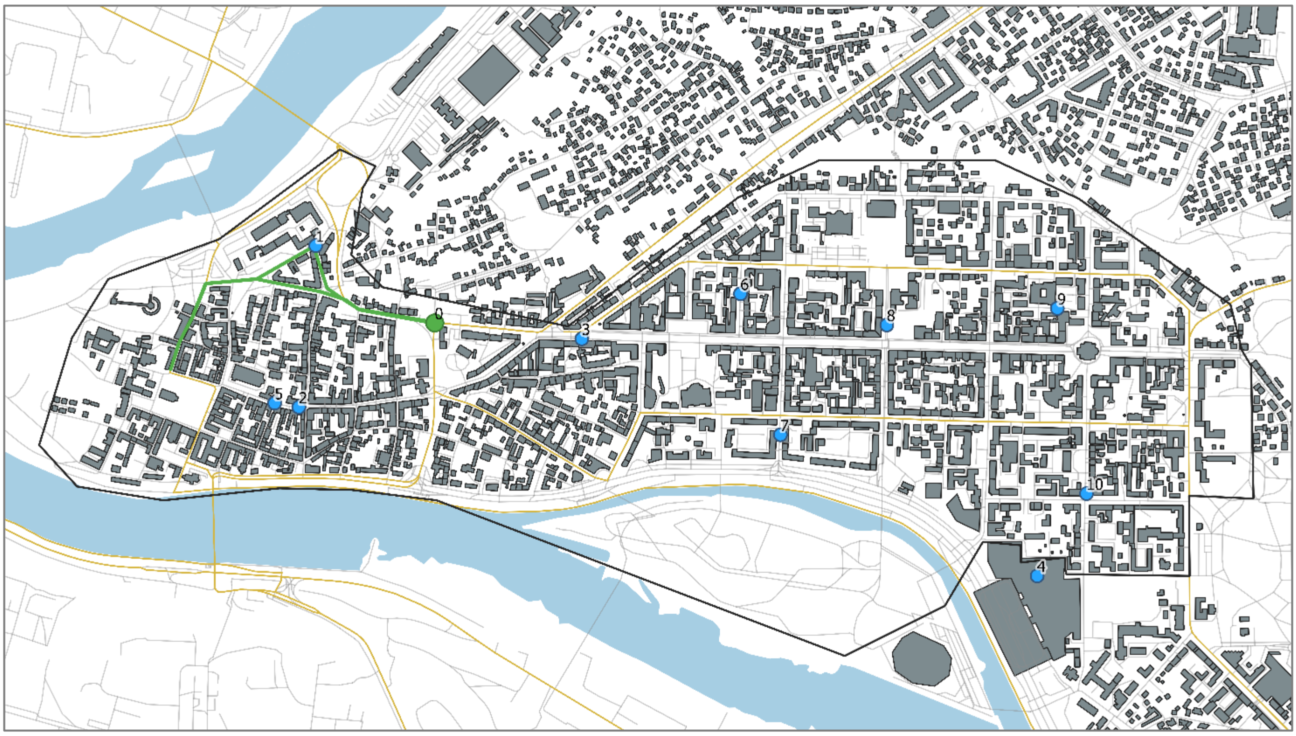


- Vehicle 4

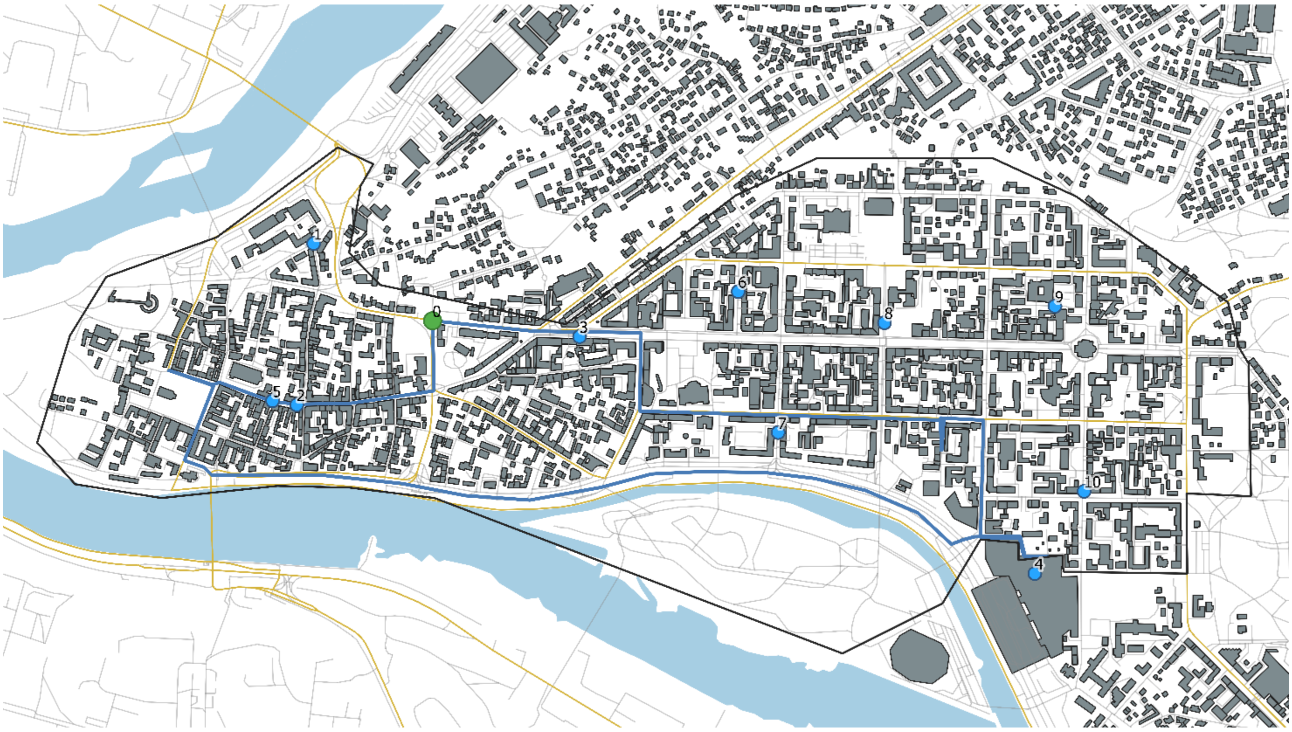


Routes from 10:30 am to 4:30 pm

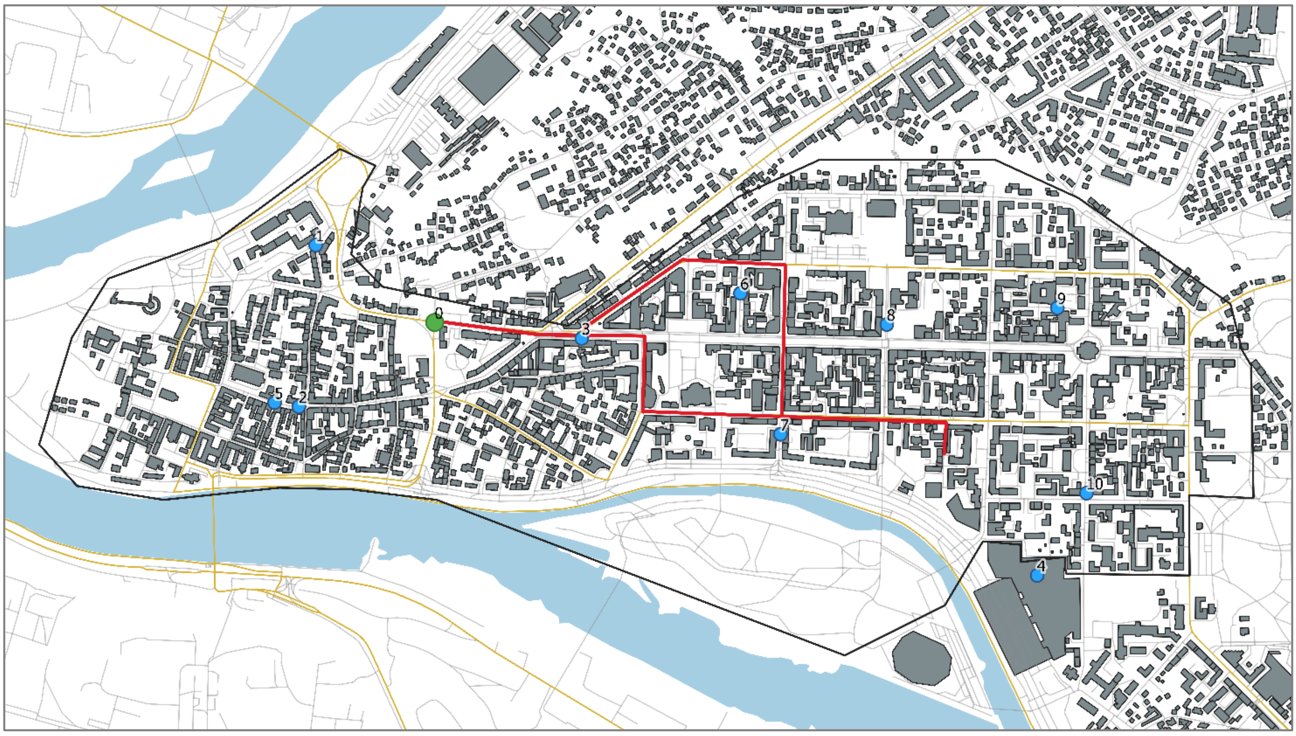
- Vehicle 1



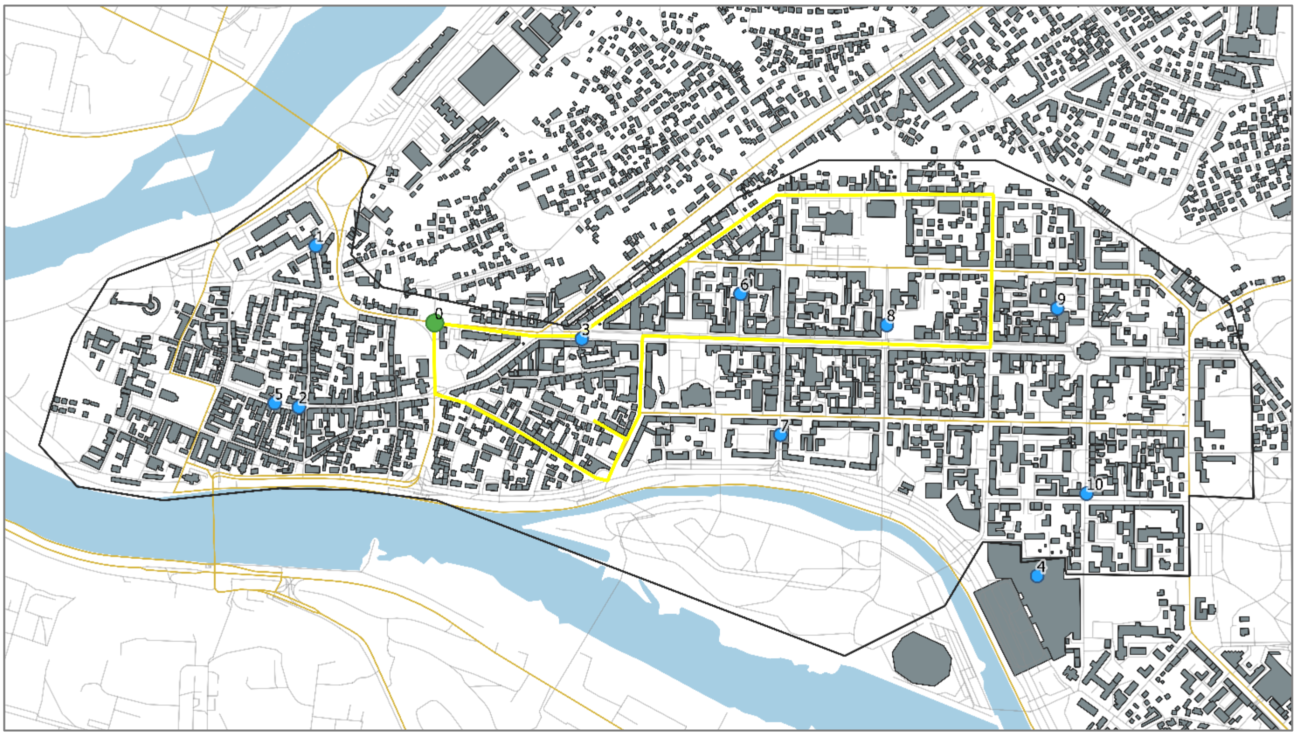
- Vehicle 2



- Vehicle 3

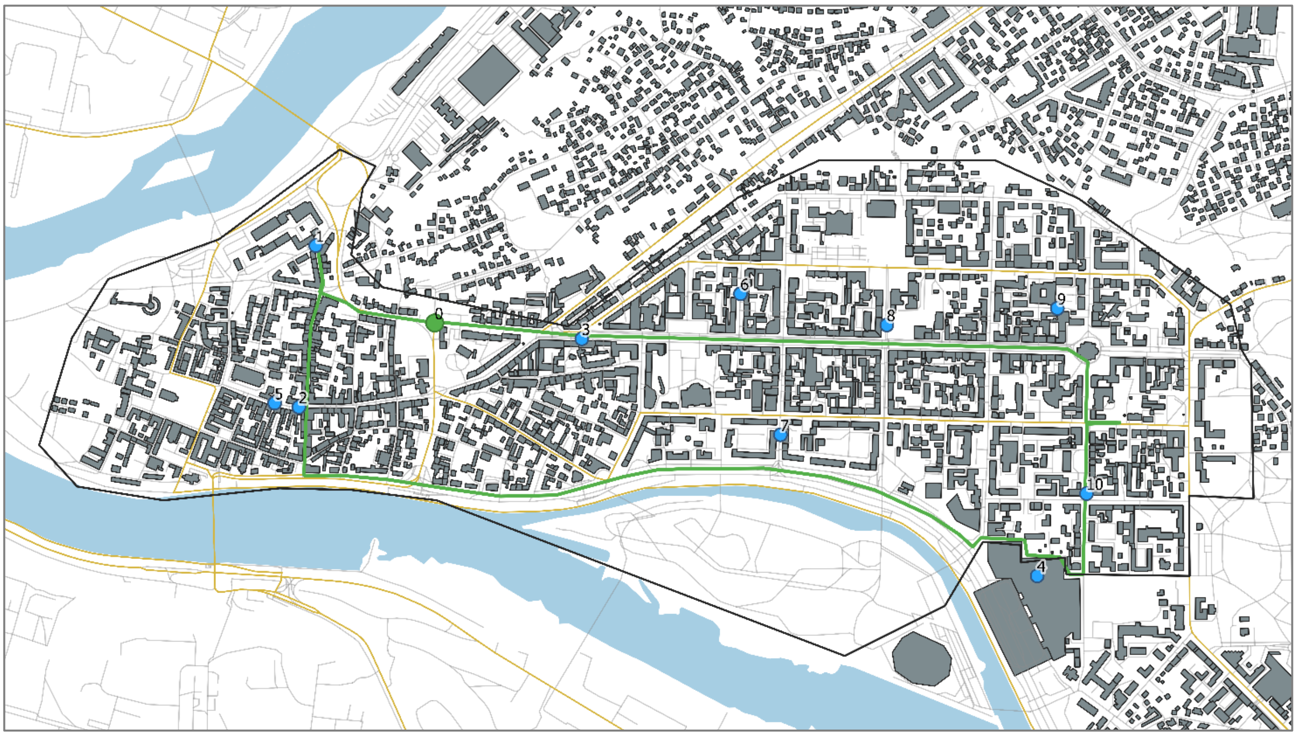


- Vehicle 4

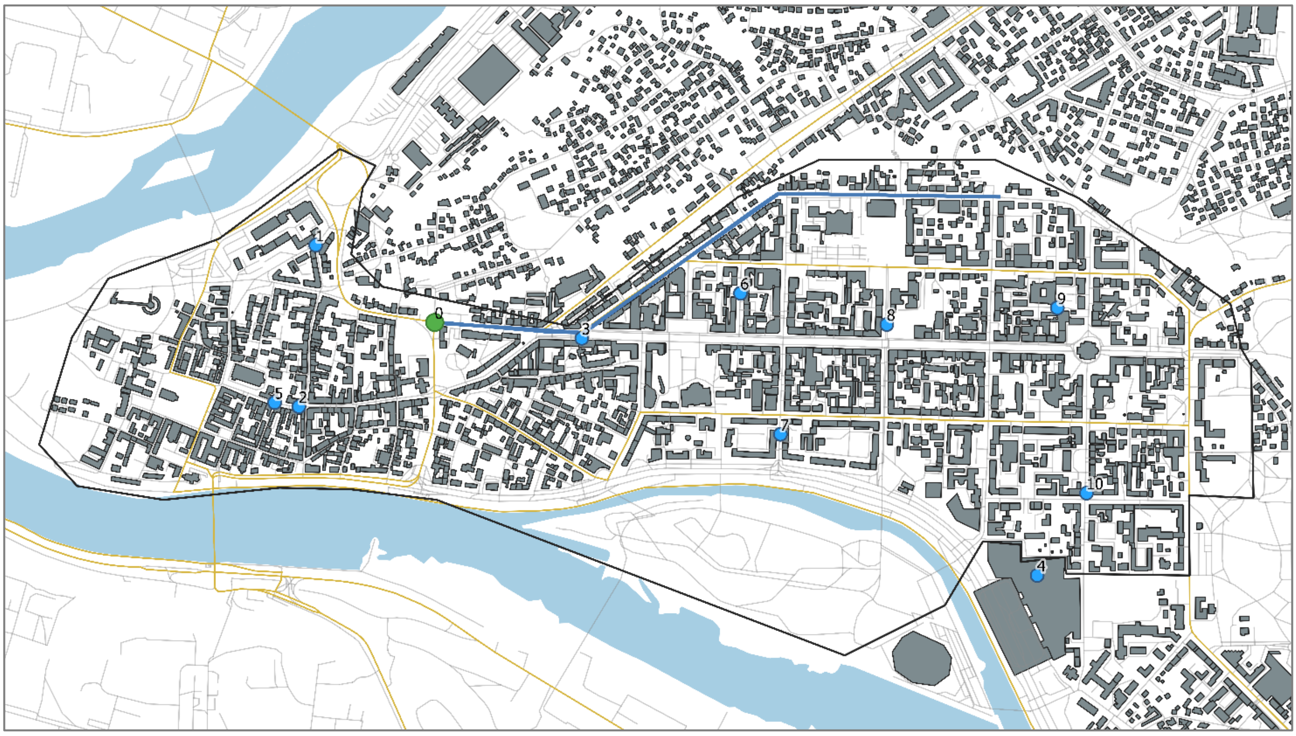


Routes from 4:30 pm to 9:00 pm

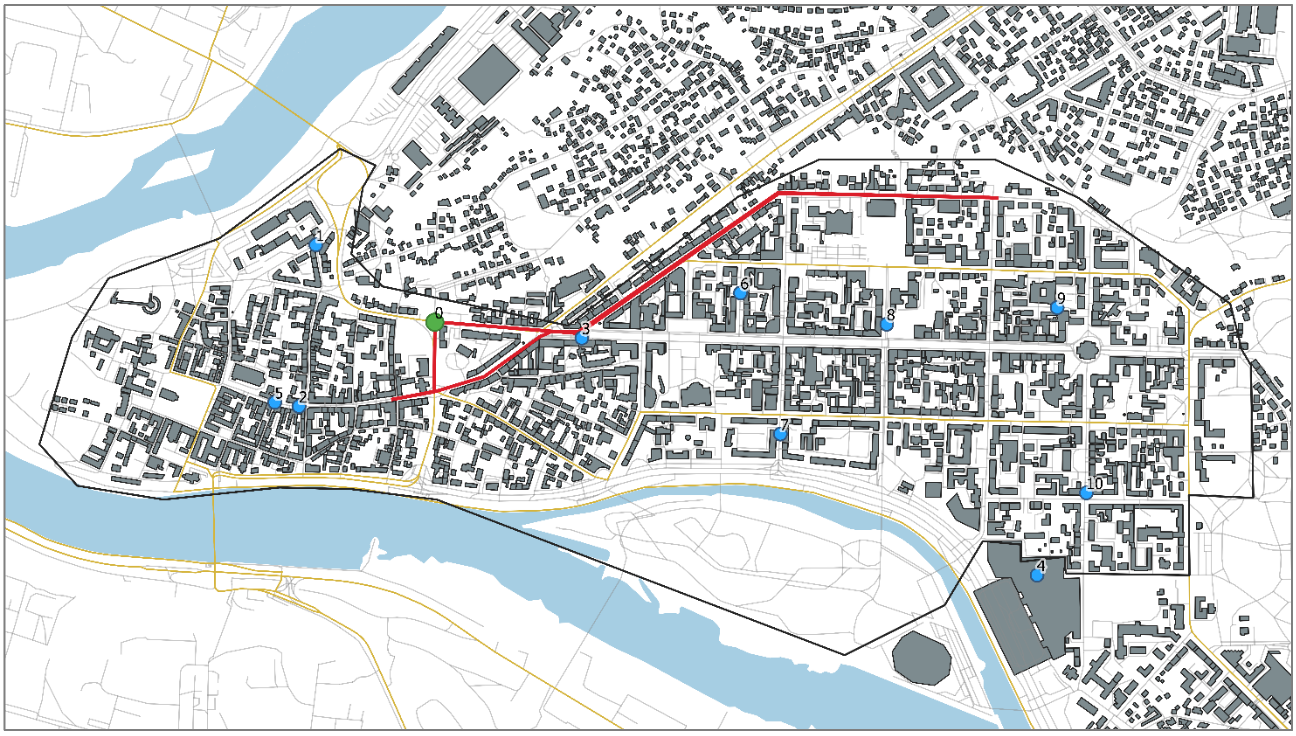
- Vehicle 1



- Vehicle 2



- Vehicle 3



- Vehicle 4